



The discard ban and its impact on the MSY objective on fisheries-the North Sea

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**RESEARCH FOR PECH
COMMITTEE - THE DISCARD BAN
AND ITS IMPACT ON THE
MAXIMUM SUSTAINABLE YIELD
OBJECTIVE ON FISHERIES**

WORKSHOP



DIRECTORATE-GENERAL FOR INTERNAL POLICIES
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FISHERIES

**RESEARCH FOR PECH COMMITTEE - THE
DISCARD BAN AND ITS IMPACT ON THE
MAXIMUM SUSTAINABLE YIELD
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WORKSHOP

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FISHERIES

**RESEARCH FOR PECH COMMITTEE -
THE DISCARD BAN AND ITS IMPACT ON
THE MAXIMUM SUSTAINABLE YIELD
OBJECTIVE ON FISHERIES**

WORKSHOP

Abstract

This is the reference document of the Workshop on "The discard ban and its impact on the Maximum Sustainable Yield objective on fisheries" of 16 th June 2016, organised by the Committee on Fisheries (COMPECH) and the Policy Department B (PECH Research) of the European Parliament.

It is structured in three parts:

- 1 The discard ban and its impact on the MSY objective-The North Sea
 2. The discard ban and its impact on the MSY objective-The Atlantic Ocean: The Bay of Biscay case
 3. The discard ban and its impact on the MSY objective-The Baltic Sea
- An Overarching report on the commonalities and differences of the three reports is attached.

May 2016

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Overarching report

Authors: Raul Prellezo, Sarah Kraak and Clara Ulrich

INTRODUCTION

The three reports, on the North Sea, the Baltic Sea, and the Atlantic Ocean (Bay of Biscay), have commonalities as well as differences, both in terms of the topics covered and in terms of the findings and conclusions. In this document we will highlight these differences and commonalities.

First of all, the **North Sea** report provides helpful background information on the concept of MSY, its history, novel extensions of the **MSY concept** (e.g. MMSY) and their problems. Likewise, the **Baltic Sea** report provides a general section on **implementation error** and on how the **behavioural sciences** may be of help to reduce this. This general information is applicable to all three reports.

The reports on the **North Sea and the Bay of Biscay**, but not the report on the Baltic Sea, include extensive discussion of **modelling studies and results**. The authors of the Baltic Sea report had agreed with the client on forehand that they would not include such modelling studies; their arguments for this decision are at the bottom of page 12 of their report.

The reports on the North Sea and the Bay of Biscay, but not the report on the Baltic Sea, provide extensive discussion of mixed-fisheries and **choke-species** aspects (and related **concepts of pretty good yield (PGY) and F-MSY ranges**). The authors of the **Baltic Sea** report did not include these aspects because a report devoted to these matters, commissioned by the European Parliament, was already prepared in the summer of 2015.

The report on the **Baltic Sea**, but not the reports on the North Sea and the Bay of Biscay, includes sections on **recreational fisheries** and other anthropogenic factors. In the case of the Bay of Biscay, although, as mentioned in the report, the impact of recreational fishery is increasing for some particular stocks, it still cannot be considered as a major factor on the ecosystem future evolution. In the North Sea, recreational fisheries and other anthropogenic factors are likely important mainly for the English Channel and coastal areas rather than the main North Sea.

It can also be noted that there is considerable scientific activity related to the Marine Strategy Framework Directive and Good Environmental Status, so information on the topic of anthropogenic factors is available elsewhere. Furthermore this was not an explicit request in the given TORs.

Most of the statements in the **North Sea** report on **biological interactions** are also valid for the Baltic Sea. Nevertheless, it should be noted that the food web is much simpler in the Baltic Sea compared to the North Sea.

On the topic of the **impact of reduced discards**, the statement that the main threat is from increased predation by scavenger seabirds on other seabird species (in the North Sea report) is probably not transferable to the Baltic Sea, because the main scavenging seabirds in the Baltic are herring gulls, which also feed on dumping sites and are not as big as greater black-backed gulls or skuas in the North sea. It should also be noted that the amount of discards falling under LO is much lower in the Baltic compared with the situation in North Sea.

CONCLUSION

All three groups of authors, of the North Sea, Baltic Sea, and Bay of Biscay reports, agree that the landings obligation (LO) and catch quotas should provide **incentives for change** in the fisheries, including adaptation through taking up **selective gears and spatiotemporal effort reallocation**, but also quota redistribution within and between member states (**swapping**). However, these incentives will only manifest if the LO and catch quotas are fully enforced. If they are not fully enforced, there will be an incentive to continue discarding. Because it is not known to what extent the LO and catch quotas will be enforced it is not known whether the incentives for change will manifest, and therefore the future behaviour of the fisheries cannot be predicted. However, bio-economic models need an assumption on future fishery behaviour. Without any evidence of change, the most obvious choice for such an assumption so far is the assumption of no change in fishing patterns. Therefore, many models were based on the assumption that catchability in the future would be the same as in the recent past. This assumption has led to the situation that if one species **chokes** the fishery the fishing opportunities for other species are **underutilised**. Whether this will in actual fact happen is not known. **Two other possible outcomes** could be the continuation of over quota discarding, or **adaptive change in fishing patterns** leading to a better balance between quotas and catches. However, predictions of these outcomes cannot be quantified because no justifiable assumption on fisher behaviour can be made.

The **Baltic Sea** report contains a chapter on important aspects regarding governance and drivers of (non-) compliance. This part is largely generic and the considerations given can apply to most fisheries.

The table below summarizes some commonalities and differences between the reports

	Baltic Sea	North Sea	Atlantic Ocean (Bay of Biscay)
	Characteristics of the area analyzed		
Structure of the ecosystem	Relatively simple.	Relatively Complex.	Relatively Complex.
Fishing fleet	Relatively Simple	Relatively Complex	Relatively Complex
	Objectives covered		
Objectives in fisheries	Multispecies approach	Mixed fisheries approach and LO	Mixed fisheries approach and LO
Objectives in management	Stability of yield. Minimization of the implementation error.	F ranges LO	Stability of yield. F ranges LO
Drivers in ecosystem impacts	Eutrophication, pollution, coastal degradation, species introduction and climate change.	Not considered.	Not considered.
	LO	LO	LO
Other Objectives covered	Impact of recreational fisheries	Not considered	Not considered Mentioned the growing impact of recreational fisheries

Results			
Results at stocks	There is no biological optimal solution. Including recreational fisheries is important.		
Results at stocks level of LO	Slightly higher biomass	Fishing mortalities below F_{MSY} . LO not fully evaluated	Fishing mortalities below F_{MSY} . LO not fully evaluated
Results at fleet level of LO	Not considered	Economic consequences very variable across fleet segments. Not easy to anticipate fleet reaction	Economic consequences very variable across fleet segments. Not easy to anticipate fleet reaction
Results at ecosystem level of LO	Effects of discards are little known, but amount of discards is relatively small. Might not threaten scavengers. Effects on benthos unknown	Effects of discards are little known. Might not threaten scavengers.	Effects of discards are little known. Might threaten scavengers.
Results from the implementation side	Fully documented fisheries (FDF) and not FDF should be treated differently. Complex top-down control and lack of trust undermine intrinsic motivation of fishermen to comply with regulations. Recommendations to increase this intrinsic motivation.	Briefly considered	Not considered
Recommendations			
Recommendation from the objectives side	Include other objectives than MSY, e.g. stability of yield.	Prioritize: MSY is the most important goal. Acknowledge the variable nature of it.	Consider the ecosystem as whole system Make room to the economic and social objectives Increase the number of assessed stocks Focus management more on the mixed and multispecies characteristic of the fishery.

Recommendation from the governance side	Use findings from behavioral sciences. Increase self-decision. Increase trust by e.g. simpler legislation. Transition to it may take many years.		No
Recommendation from the institutional side	Incentivize the organization of fishers into groups. Allow for several levels of organization to choose from and allow for self-selecting of group membership.	Smart and transparent use of MSY ranges. Keep the institutional sustainability and reactivity. Support the legitimacy of landing obligation. Be precautionary	Define MSY in a flexible way. Adaptability can boost unexpected opportunities. Focus not only in simulation but in data quality. EBM is not more risky than current Fisheries management

DIRECTORATE-GENERAL FOR INTERNAL POLICIES
POLICY DEPARTMENT B: STRUCTURAL AND COHESION POLICIES

FISHERIES

**THE DISCARD BAN AND ITS IMPACT ON
THE MSY OBJECTIVE ON FISHERIES-THE
NORTH SEA**

STUDY

Abstract

North Sea fisheries are characterised by numerous biological and technical interactions, which create difficulties in identifying MSY targets and achieving those for all stocks simultaneously. The landing obligation may reinforce these issues, as 'choke' effects might be triggered by the least productive stocks. A flexible management approach can help achieve the multiple objectives, but this requires trade-offs to be made. The ecological benefits of reducing fishing mortality are likely larger than those from the landing obligation itself.

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LIST OF ABBREVIATIONS

BH	Balanced Harvesting
B_{MSY}	Spawning stock biomass (SSB) that results from fishing at F_{MSY} for a long time
B_{lim}	Limit reference point for spawning stock biomass (SSB)
CFP	Common Fishery Policy
DiscardLess	European Research Project from the Horizon2020 Framework Program, "Strategies for the gradual elimination of discards in the European fisheries", Grant Agreement 633680, www.discardless.eu)
DLS	Data Limited Stocks
DST	Decision Support Table
EWE	Ecopath with Ecosim model
F_{MSY}	Fishing mortality consistent with achieving Maximum Sustainable Yield (MSY)
FP.05	Precautionary fishing mortality achieving a 5% risk of falling below Blim
GES	Good Environmental Status
ICES	International Council for the Exploration of the Sea
ITQ	Individual Transferable Quota
LO	Landings Obligation
MCRS	Minimum Conservation Reference Size
MEY	Maximum Economic Yield
MLS	Minimum Landing Size
MSFD	Marine Strategy Framework Directive
MSY	Maximum Sustainable Yield
MSY_v	Maximum Sustainable Yield in value
MSY_w	Maximum Sustainable Yield in weight
MSY B_{trigger}	Value of spawning stock biomass (SSB) that triggers a specific management action
MYFISH	European Research Project from the 7 th Framework Program, "Maximising yield of fisheries while balancing ecosystem, economic and social concerns", Grant Agreement 289257, www.myfishproject.eu)
NPV	Net Present Value
OY	Optimum Yield

PA	Precautionary Approach
PGY	Pretty Good Yield
SMS	Stochastic age-length-structured multispecies model
SRR	Stock Recruitment Relationships
SSB	Spawning Stock Biomass
STECF	EU Scientific, Technical and Economic Committee for Fisheries
SWOT	Analysis of Strengths, Weaknesses, Opportunities and Threats
WGMIXFISH	ICES Working Group on Mixed Fisheries
WGSAM	ICES Working Group on Multispecies Assessment Methods

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EXECUTIVE SUMMARY

Background

The provisions of the reformed Europe's Fisheries Policy (CFP) reflected in the Regulation (EU) No 1380/2013 sets the stage for fishery managers and stakeholders to take the initiative and responsibility to complement and implement plans for managing fisheries within their region. For the purpose of implementing the provisions of the CFP, the discard ban and the MSY objective, and to facilitate management by these parties, relevant knowledge needs to be developed, accessed and deployed in each regional context.

The European Parliament's Committee on PECH wishes to commission a research study on the topic, and at regional level one of them is: "The North Sea- The discard ban and its impact on the MSY objective".

Aim

The study-in depth will conduct in EU waters in the Atlantic Ocean/North Sea/Baltic Sea, a specific case- study, to get the relevant knowledge to implement the discard plans and multiannual plans, managing the harvested stocks to levels that can produce the MSY, taking into account the ecosystem.

The study will be based on the best suitable existing data for the bio-economic model, obtained from the fishing fleets operating in the marine area defined for the case-study

The approach will be through the scientific models available to simulate biological marine scenarios in order to obtain different practical options.

The study will conduct a summary report of the state for the art scientific knowledge on the above objectives and describe and analyse the following topics:

1. A summary of the current state of MSY modelling in the region, including specific outcomes and main conclusions The summary will identify and analyse objectives, stocks and fleets, interactions, uncertainties, according to the indicators used. It will also produce an assessment of those elements not included and their likely influence in reaching the objectives of the CFP in the short and medium term.
2. A quantitative bio-economic analysis based on a case-study in the region on the likely consequences of the landing obligation regarding the objectives of the CFP, specially the MSY. For this purpose, different scenarios and/or practical options should be identified and assessed, considering risks, uncertainties and the main interactions.
3. A qualitative and if possible quantitative assessment of the main impacts that landing obligation in the context of the MSY may have in the whole ecosystem of the region, identifying and analysing the related uncertainties.
4. Based on these analyses, recommendations will be made to the European Parliament providing the knowledge on the best way to implement the discards plans and multiannual plans according to the different scenarios at regional level.

Main findings

This report summarises a vast amount of scientific knowledge developed by **several North Sea research institutes** over time, bringing the most up-to-date findings across the various Terms of Reference.

The North Sea is a particularly interesting area for **fisheries science**, with regards to two features: **(i)** its **complexity**, which raises important issues and triggers questions, and **(ii)** the **quantity and quality of knowledge** and data available, which allow in depth analyses and the emergence of new thinking. The **state** of the main **stocks** is fairly well known. The fishing mortality on the main stocks has decreased significantly since the beginning of the XXIst century and the biomass has increased, but the recruitment remains poor compared to historical observations.

The area is characterised by its **multiple** biological (predator-prey) and technical (mixed-fisheries) interactions, and both types have been extensively studied over time. There are many models of medium complexity available, which focus on different aspects and processes of the North Sea ecosystem and of the fisheries that exploit it. The reductions in fishing effort mean that **natural mortality is becoming a major source of mortality** in the North Sea, and the stock dynamics are increasingly influenced by natural processes and not by fisheries only.

Regarding the current state of MSY modelling in the region, it is noted that the North Sea has traditionally been the most studied and modelled area in European fisheries, but efforts to define and estimate MSY have been intensified over the last five years. The productivity and growth of North Sea stocks is variable, not least with significant decreases in the last two decades potentially linked to climate change. As a consequence MSY and F_{MSY} for a single stock can vary considerably across various combinations of biological parameters. A generic framework has been developed to estimate an **average long-term F_{MSY} for the main stocks**. This framework has shown that similar high and sustainable long-term yields can potentially be achieved with different values of fishing mortality.

The concept of MSY in a wider North Sea ecosystem and/or mixed-fisheries regional approach is much more complex. Issues in identifying **MSY beyond the single-stock concept** are both a matter of definition (how to define Yield, Maximum and Sustainable when there are many variable and interacting stocks?) and a matter of quantification (which processes and assumptions are included in the various models available?). A lot of these questions have been investigated during the EU FP7 research project MYFISH¹. **Three different definitions** of MSY have been quantified and compared (**MSY in tonnage MSYw, MSY in monetary value MSYv, and MEY, maximum net present value**) when accounting for three different processes (biological predator-prey relationships; technical interactions in mixed-fisheries; and interactions with sensitive bycatch species). A main outcome was that MSYw may lead to undesirable outcomes such as loss in profit and conflicts with environmental constraints. MEY seems to be a more appropriate concept to cover wider objectives, but would come at the cost of lower fishing effort and thus employment.

¹ www.myfishproject.eu

These **trade-offs** led to the idea that a “**Pretty Good Yield**” (**PGY**) (Or Optimum Yield OY) concept may be more suitable instead of trying to define and reach the absolute maximum. The PGY means that a part of the maximum yield could be traded off against the achievement of the other objectives, in particular with regards to mixed-fisheries conflicts in the frame of regional management plans and the landing obligation. **Single-stock PGY** has been operationalised through **F_{MSY} ranges** providing at least 95% of the maximum yield, but ICES emphasizes that fishing above F_{MSY} bears some **ecological and economic costs**.

Regarding a quantitative bio economic analysis on the likely consequences of the landing obligation, the linkages between MSY and the landing obligation are first investigated. It is argued that the **landing obligation is not a direct mean** to achieve MSY, but rather an **objective** in itself. **Several North Sea stocks are already fished at F_{MSY}** in spite of sometimes important discards. Many bio-economic impact assessments have been performed on several North Sea **mixed-fisheries fleets**. They mainly highlight the impact of “**choke species**”, where the early TAC exhaustion of the least productive stock (which can be either a target e.g. cod, sole or whiting or a bycatch e.g. turbot) or of a stock with limited historical fishing rights in the region (e.g. hake) would lead to fishery closure and under-exploitation of the more productive stocks. The increased fishing costs are also estimated. The various **policy adjustments** possible in the frame of the landing obligation can though mitigate or even nullify the short-term negative economic impact for some fleets. Additionally, it is noted that with the recovery of the North Sea cod, some “choke effects” might be less severe than predicted by the available **economic models**.

There are many ways by which **fishers** could improve their fishing patterns to better adjust to fishing opportunities. Many options already exist, and new industry-led solutions could be developed. But proper **mechanisms incentivising** them to do so are needed; otherwise the risks of **non-compliance** are real. At this stage, it is thus not possible to predict how the fishing industry will actually react, as the voluntary uptake of selective gears has historically been limited. New empirical experience will be gained over the next five years.

Regarding an assessment of the main ecosystem impacts of the landing obligation, it is noted that the scientific knowledge is still uncertain. **Seabirds and benthic scavengers** are the main populations feeding on discards, but the cascading effects further up in the foodweb are limited. It is considered that the populations of scavengers are potentially rather large. So it is assumed that they might be able to buffer the food shortage linked to the landing obligation; although some studies have pointed out that a **gradual reduction of discards** might be better for the ecosystem stability than an abrupt elimination. The main threat identified is whether the opportunistic scavengers will increase predation and domination on more sensitive species, mainly among seabirds. It is suspected that *Nephrops* stocks could have been enhanced by fish discards, but the scientific evidence for this is weak and observations are scarce.

More generally, the landing obligation has fuelled an important scientific debate regarding whether selective fishing on adults is ecologically preferable to the catching of juveniles in a “**balanced harvesting**” approach. This question is still unresolved, and balanced harvesting is probably not fully operational technically and economically in mixed fisheries like those in the North Sea. Nevertheless, this challenges the established paradigm of concentrating fishing mortality on few adult age classes of few commercial species. Ultimately, it is argued that the most important ecological benefits are obtained by limiting fishing mortality (and thus fishing effort) in the first place. **A low fishing mortality reduces the importance of other factors such as size- and species-selectivity.**

Regarding recommendations, we argue that **MSY** is and remains the most important CFP **objective** for sustainable European fisheries, in spite of the many criticisms raised against it. But we acknowledge its fuzzy and variable nature, especially when considered at the scale of the entire **eco-region**. This requires some **policy trade-offs** to be made when it is not possible to achieve all ecological, economic and social objectives at the same time.

We acknowledge that the **MSY ranges** can be a pragmatic formal frame buffering the worst negative impacts when choke effects occur in mixed-fisheries. It could potentially improve the governance around the annual TAC setting compared to the situation observed with e.g. North Sea cod over the last few years. Nevertheless, it is understood that TACs should **not be blindly and systematically set at the F_{upper} level**, which would not solve the basic **mixed-fisheries issues**. We recommend following a smart and transparent use, and suggestions for these are explored briefly. One option might be for example to **choose F_{MSY}** as the default option for setting the annual fishing opportunities, and to allow for deviation from it within the range only on the basis of obvious and documented short-term conflicts (**ecological, economic, social or political**).

Ultimately, we consider that in the light of the many uncertainties facing European fisheries during the transition years from now to 2020, it is likely appropriate to ensure that in any case, **fishing effort** should not increase back to the high levels observed up to a decade ago, which would surely prevent reaching any of the **CFP objectives**.

1. GENERAL INFORMATION

KEY FINDINGS

- The North Sea is a **data-rich area** with a large amount of data and models available
- ICES provides information on **55 stocks in the North Sea ecoregion**, of which 22 are assessed using a full analytical assessment and 14 are assessed with biomass trends from scientific surveys only. 12 of the stocks with full assessment were assessed to be above MSY $B_{trigger}$ in 2015.
- In 2015, **discard information was available** for most of the stocks.
- The North Sea fisheries can be characterised by **many complex interactions**, both **biologically** (predator-prey relationships) and **technically** (species being caught together in mixed fisheries).
- Because of this, the North Sea fisheries have long been considered at **regional level** in addition to single-stock assessment.

1.1. A complex area with high level of scientific knowledge

The North Sea is a particularly interesting area for fisheries science, with regards to **two features**: **(i) its complexity**, which raises important issues and triggers questions, and **(ii) the quantity and quality of knowledge** and data available, which allow in depth analyses and the emergence of new thinking. The area is characterised by its multiple **biological** (predator-prey) and **technical (mixed-fisheries)** interactions, and both types have been extensively studied over time. The North Sea has therefore long been apprehended at its large regional scale and not only as a suite of independent stocks to be managed individually. This global understanding has triggered the development of **many scientific models**, which all build on the same broad principles of population dynamics, but which also have conceptualised and explored the interactions in multiple and diverse ways; none of these models being able to capture the full diversity and complexity of the processes driving the North Sea ecosystem, but only a subset.

One of the **challenges** in this current study has thus been **to synthesize a very vast amount of scientific knowledge** developed by scientists from numerous institutions from the eight countries surrounding the North Sea, across widely different fields of fisheries and marine science. No new specific modelling work has been developed for this study; rather, salient results have been selected from the existing published literature and many ICES reports. The tables and figures presented below are therefore picked up from a variety of independent studies and models, and are not always directly comparable with each other. Incidentally, this diversity of scientific investigations is another important source of complexity in itself. On the one hand, having a fair amount of **different models** is a great **advantage** as this allows critical evaluation of models' assumptions and a more complete understanding of the uncertainties associated with outcomes. On the other hand, it makes it sometimes difficult for the scientific community to convey a simple and unique message. In this sense, the International Council for the Exploration of the Sea (**ICES**) plays a **fundamental role in bringing this vast knowledge together** and operationalising it for useful advice.

Most of the work on MSY presented here draws knowledge from the FP7 EU Project MYFISH² (*Maximising yield of fisheries while balancing ecosystem, economic and social concerns*, Grant Agreement 289257), that started in 2012 and finished in February 2016. This study represents therefore a synthesis of the most recent state-of-the art knowledge on MSY in the North Sea region. Additionally, insights on the landing obligation are being gathered as part of the ongoing H2020 EU Project DiscardLess³ (*Strategies for the gradual elimination of discards in the European fisheries*, Grant Agreement 633680, 2015-2019). As a consequence some of the work presented here refers to most recent studies that are not published yet or are still ongoing. Other studies not related to these two projects are presented, but this review might not be a fully exhaustive list of the scientific knowledge available.

1.2. MSY, F_{MSY} and B_{MSY}

In the following document, we will systematically refer to the following **definitions** as used by ICES⁴:

- B_{MSY} :** Spawning stock biomass (SSB) that results from fishing at F_{MSY} for a long time
- F_{MSY} :** Fishing mortality consistent with achieving Maximum Sustainable Yield (MSY)
- MSY:** Maximum Sustainable Yield: the largest average catch or yield that can continuously be taken from a stock **under existing environmental conditions**.

ICES does not estimate B_{MSY} though, because of long **controversies** on this reference point. Until fishing has been stabilised long enough at F_{MSY} to get a better knowledge of the actual productivity of stocks at lower exploitation rates, which would allow a more reliable estimate of B_{MSY} , ICES rather refers to B_{FMSY} .

If not specified, the generic term “**MSY modelling**” refers to the global approach of identifying **MSY, F_{MSY} and/or B_{FMSY} using scientific models**. Otherwise, the expressions “**achieving MSY**” or “**being at MSY**” refer to the objective of the Common Fishery Policy to achieve the maximum sustainable yield exploitation rate for all stocks (European Parliament and Council of the European Union, 2013), and they are thus **expressed in term of fishing mortality F compared to F_{MSY}** .

1.3. Overview of North Sea stocks

In 2015, ICES provided information on **55 stocks in the North Sea ecoregion** (Table 1). The stocks are categorised according to the type of assessment model used to produce their catch advice, which itself depends upon the quality and the quantity of **biological and fishery data** available. This categorisation has commonly been referred to the DLS (Data-Limited Stocks) categories (NB this labelling is expected to be renamed differently in 2016), ranging from 1 to 6 (ICES, 2015a). In the North Sea ecoregion, **22 stocks** are assessed **analytically** (i.e. with a full quantitative assessment model and a forecast, DLS Category 1) and **14** are assessed with **biomass trends** from scientific surveys only (DLS Category 3.2). **The rest** is assessed on the basis of **catch data** only. At present, ICES provides MSY-based advice only for the stocks of categories 1 and 2. Advice for the other categories is still based on the Precautionary Approach (see chapter 2.2.2). **12 stocks** of category 1 were assessed to be **above MSY $B_{trigger}$ in 2015**, and 6 were estimated below. 4 stocks have an undefined MSY $B_{trigger}$.

² www.myfishproject.eu

³ www.discardless.eu,

⁴ http://www.ices.dk/community/Documents/Advice/Acronyms_and_terminology.pdf

Table 1. List of stocks assessed by ICES in 2015 in the North Sea Sea EcoRegion, together with the DLS assessment category.

For the stocks of category 1 (full assessment), the DLS colour highlights the biomass level relative to $MSY_{B_{trigger}}$ according to the ICES Advice in 2015. Green: Above $MSY_{B_{trigger}}$. Red: Below $MSY_{B_{trigger}}$. Darker Grey: $MSY_{B_{trigger}}$ undefined.

STOCK CODE	SPECIES	SCIENTIFIC NAME	ICES STOCK NAME	DLS
bll-nsea	Brill	<i>Scophthalmus rhombus</i>	Brill in Subarea IV and Divisions IIIa and VIIId,e	3.20
cod-347d	Cod	<i>Gadus morhua</i>	Cod in Subarea IV (North Sea) and Divisions VIIId (Eastern Channel) and IIIa West (Skagerrak)	1.00
cod-kat	Cod	<i>Gadus morhua</i>	Cod in Division IIIa East (Kattegat)	3.20
dab-nsea	Dab	<i>Limanda limanda</i>	Dab in Subarea IV and Division IIIa	3.20
fle-nsea	Flounder	<i>Platichthys flesus</i>	Flounder in Division IIIa and Subarea IV	3.20
gug-347d	Grey gurnard	<i>Eutrigla gurnardus</i>	Grey gurnard in Subarea IV (North Sea) and Divisions VIIId (Eastern Channel) and IIIa (Skagerrak–Kattegat)	3.2q
had-346a	Haddock	<i>Melanogrammus aeglefinus</i>	Haddock in Subarea IV and Divisions VIa and IIIa West (North Sea, West of Scotland, Skagerrak)	1.00
her-3a22	Herring	<i>Clupea harengus</i>	Herring in Division IIIa and Subdivisions 22–24 (western Baltic spring spawners)	1.00
her-47d3	Herring	<i>Clupea harengus</i>	Herring in Subarea IV and Divisions IIIa and VIIId (North Sea autumn spawners)	1.00
hom-nsea	Horse mackerel	<i>Trachurus trachurus</i>	Horse mackerel in Divisions IIIa, IVb,c, and VIIId (North Sea stock)	5.20
lem-nsea	Lemon sole	<i>Microstomus kitt</i>	Lemon sole in Subarea IV and Divisions IIIa and VIIId	3.20
mur-347d	Striped red mullet	<i>Mullus surmuletus</i>	Striped red mullet in Subarea IV (North Sea) and Divisions VIIId (Eastern English Channel) and IIIa (Skagerrak–Kattegat)	3.20
nep-10	Norway lobster	<i>Nephrops norvegicus</i>	<i>Nephrops</i> in Noup (FU 10)	4.14
nep-32	Norway lobster	<i>Nephrops norvegicus</i>	<i>Nephrops</i> in the Norwegian Deep (FU 32)	4.14
nep-33	Norway lobster	<i>Nephrops norvegicus</i>	<i>Nephrops</i> off Horn's Reef (FU 33)	4.14
nep-34	Norway lobster	<i>Nephrops norvegicus</i>	<i>Nephrops</i> in Devil's Hole (FU 34)	4.14
nep-3-4	Norway lobster	<i>Nephrops norvegicus</i>	<i>Nephrops</i> in Division IIIa	1.00
nep-5	Norway lobster	<i>Nephrops norvegicus</i>	<i>Nephrops</i> in Botney Gut–Silver Pit (FU 5)	4.14
nep-6	Norway lobster	<i>Nephrops norvegicus</i>	<i>Nephrops</i> in Farn Deep (FU 6)	1.00
nep-7	Norway lobster	<i>Nephrops norvegicus</i>	<i>Nephrops</i> in Fladen Ground (FU 7)	1.00
nep-8	Norway lobster	<i>Nephrops norvegicus</i>	<i>Nephrops</i> in Firth of Forth (FU 8)	1.00
nep-9	Norway lobster	<i>Nephrops norvegicus</i>	<i>Nephrops</i> in Moray Firth (FU 9)	1.00
nep-oth-4	Norway lobster	<i>Nephrops norvegicus</i>	Norway lobster (<i>Nephrops spp.</i>) in Division IV, outside the Functional Units (North Sea)	5.00
nop-34	Norway pout	<i>Trisopterus esmarkii</i>	Norway pout in Subarea IV (North Sea) and Division IIIa (Skagerrak–Kattegat)	1.00
pan-flad	Northern shrimp/ prawn	<i>Pandalus borealis</i>	Northern shrimp in Division IVa (Fladen Ground)	6.30
pan-sknd	Northern shrimp/ prawn	<i>Pandalus borealis</i>	Northern shrimp in Divisions IIIa and IVa East (Skagerrak and Norwegian Deep)	1.00

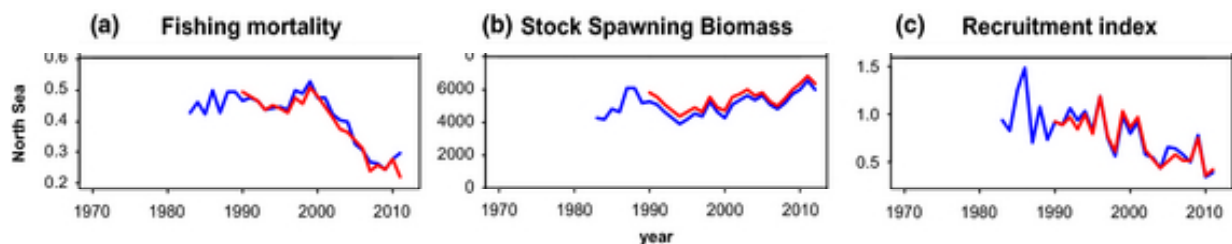
ple-eche	Plaice	<i>Pleuronectes platessa</i>	Plaice in Division VIIId (Eastern Channel)	1.00
ple-nsea	Plaice	<i>Pleuronectes platessa</i>	Plaice in Subarea IV (North Sea) and division IIIaN (Skagerrak)	1.00
pol-nsea	Pollack	<i>Pollachius pollachius</i>	Pollack in Subarea IV and Division IIIa	5.20/ 3.14
raj-347d	Other skates and rays	<i>Rajadai</i>	Other skates and rays in the North sea ecoregion (Subarea IV, and Divisions IIIa and VIIId)	6.20
rjb-34	Common skates	<i>Dipturus spp.</i>	Common skate in Subarea IV and Division IIIa (North Sea and Skagerrak)	6.30
rjc-347d	Thornback ray	<i>Raja clavata</i>	Thornback ray in Subarea IV, and Divisions IIIa and VIIId (North Sea, Skagerrak, Kattegat and eastern English Channel)	3.20
rjh-4c7d	Blonde ray	<i>Raja brachyura</i>	Blonde ray in Divisions IVc and VIIId (Southern North Sea and eastern English Channel)	5.20
rjm-347d	Spotted ray	<i>Raja montagui</i>	Spotted ray in Subarea IV, and Divisions IIIa and VIIId (North Sea, Skagerrak, Kattegat, and Eastern English Channel)	5.20q
rjn-34	Cuckoo ray	<i>Leucoraja naevus</i>	Cuckoo ray in Subarea IV and Division IIIa (North Sea and Skagerrak and Kattegat)	3.20
rjr-234	Starry ray	<i>Amblyraja radiata</i>	Starry ray in Subareas II, IIIa and IV (Norwegian Sea, Skagerrak, Kattegat and North Sea)	3.1.5
sai-3a46	Saithe	<i>Pollachius virens</i>	Saithe in Subarea IV (North Sea), Division IIIa (Skagerrak), and Subarea VI (West of Scotland and Rockall)	1.00
san-ns1	Sandeel	<i>Ammodytes spp.</i>	Sandeel in the Dogger Bank area (SA 1)	1.00
san-ns2	Sandeel	<i>Ammodytes spp.</i>	Sandeel in the South Eastern North Sea (SA 2)	1.00
san-ns3	Sandeel	<i>Ammodytes spp.</i>	Sandeel in the Central Eastern North Sea (SA 3)	1.00
san-ns4	Sandeel	<i>Ammodytes spp.</i>	Sandeel in the Central Western North Sea (SA 4)	3.20
san-ns5	Sandeel	<i>Ammodytes spp.</i>	Sandeel in the Viking and Bergen Bank areas (SA 5)	5.30
san-ns6	Sandeel	<i>Ammodytes spp.</i>	Sandeel in Division IIIa East (Kattegat, SA 6)	5.20
san-ns7	Sandeel	<i>Ammodytes spp.</i>	Sandeel in the Shetland area (SA 7)	5.30
sol-eche	Sole	<i>Solea solea</i>	Sole in Division VIIId (Eastern Channel)	1.00
sol-kask	Sole	<i>Solea solea</i>	Sole in Division IIIa and Subdivisions 22–24 (Skagerrak, Kattegat, and the Belts)	1.00
sol-nsea	Sole	<i>Solea solea</i>	Sole in Subarea IV (North Sea)	1.00
spr-kask	Sprat	<i>Sprattus sprattus</i>	Sprat in Division IIIa (Skagerrak – Kattegat)	3.20
spr-nsea	Sprat	<i>Sprattus sprattus</i>	Sprat in Subarea IV (North Sea)	1.00
syc-347d	Lesser-spotted dogfish	<i>Scyliorhinus canicula</i>	Lesser-spotted dogfish in Subarea IV, and Divisions IIIa and VIIId (North Sea, Skagerrak, Kattegat, and Eastern English Channel)	3.20
tur-kask	Turbot	<i>Scophthalmus maximus</i>	Turbot in Division IIIa	3.20
tur-nsea	Turbot	<i>Scophthalmus maximus</i>	Turbot in Subarea IV	3.20
whg-47d	Whiting	<i>Merlangius merlangus</i>	Whiting in Subarea IV (North Sea) and Division VIIId (Eastern Channel)	1.00
whg-kask	Whiting	<i>Merlangius merlangus</i>	Whiting in Division IIIa (Skagerrak – Kattegat)	5.20
wit-nsea	Witch	<i>Glyptocephalus cynoglossus</i>	Witch in Subarea IV and Divisions IIIa and VIIId	3.20

Source: ICES. See (ICES, 2015a) for further info on the categories.

The information on discards has improved over the years. In 2015, the ICES advice included discards considerations for most stocks. In the North Sea, **eleven stocks of category 1 have now discards** included in the **analytical assessments**, and seven of them have had that for more than ten years. For these **seven stocks**, the summed discard ratio has been around **20-25% since 2010, against 30-35%** in the period **2004-2010** (Source: ICES database⁵).

An important feature in the North Sea is that fishing mortality has **strongly reduced** since the beginning of the XXIst century for all demersal stocks (**Error! Reference source not found.**), and the summed stock biomass has increased in response. Nevertheless, the **productivity** (recruitment and recruitment-per-unit of SSB) has regularly **decreased**, and is still **now at a very low level** compared to historical observations (Gascuel *et al.*, 2014; ICES, 2015b).

Figure 1. Trends in stock-based indicators for all assessed North Sea stocks: mean fishing mortality F (a), total spawning stock biomass SSB (b, in thousand tonnes) and the mean recruitment index R (column c, relative value to the 1990–2000 average).



The red line refers to all stocks assessed in 2012, while the blue line is the longest available time series including at least 60% of assessed stocks.

Source: (Gascuel *et al.*, 2014)

1.4. An overview of the interactions influencing MSY in the North Sea

1.4.1. Biological interactions

The knowledge on foodweb is developed by the ICES Working Group on Multispecies Assessment Methods WGSAM. The North Sea is characterized by many and strong biological interactions (Figure 6), which are quantified using the SMS model parameterized on historical stomachs samples for the main commercial species (Lewy and Vinther, 2004). This knowledge has been summarized in the ICES multi species considerations for North Sea stocks (ICES, 2013) as follows:

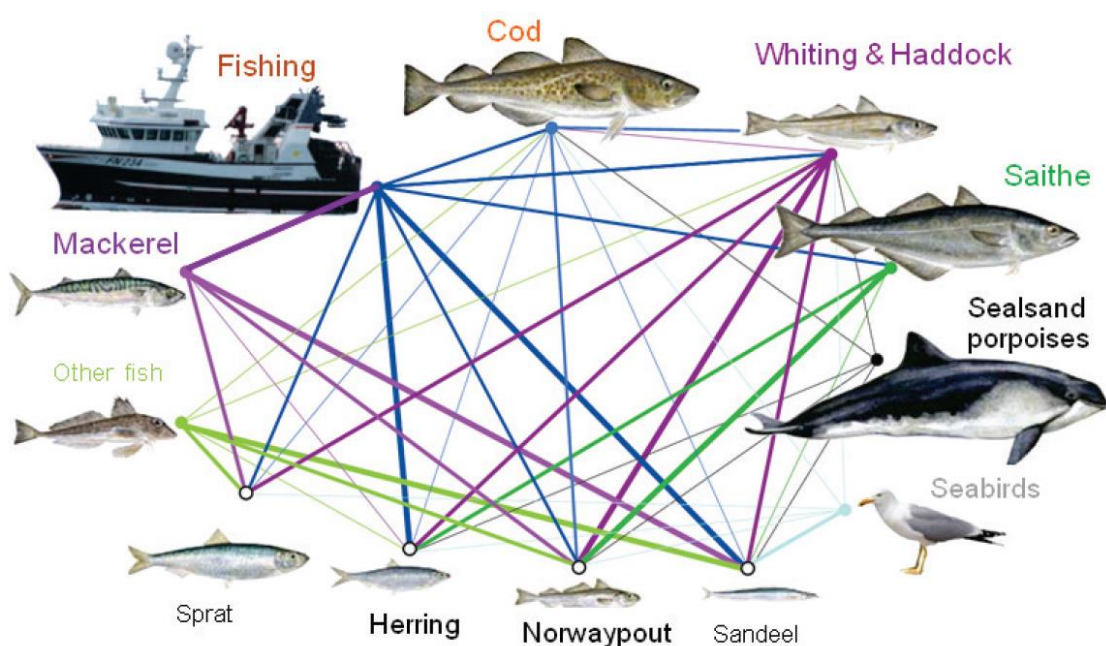
Top predators form an important part of the **food web**, including numerous charismatic species such as **seabirds and marine mammals** that eat fish. Within the fish community a number of fish eat other fish, and some of those spend only part of their time in the North Sea. The fish species can be divided into four categories: **forage** (prey) fish, fish that eat small fish, benthic-feeding fish, and fish that eat **large fish** (top predators). Forage fish feed on plankton in the water column. The majority of forage fish are also targeted directly by the fishery (*herring, sandeel, sprat, Norway pout*). Together with typical forage fish, juvenile gadoids are also an important food source in the North Sea food web. Fish that eat small fish belong to a wide range of species, including some that are targeted by fisheries (e.g. *whiting, haddock*), some that are only occasionally landed (e.g. *grey gurnard, starry ray*), and some that enter the North Sea only in specific seasons (e.g. *western horse mackerel and mackerel*).

⁵ <http://www.ices.dk/marine-data/tools/Pages/stock-assessment-graphs.aspx>.

Benthic-feeding fish include all kinds of flatfish that feed on prey in or near the bottom. The majority of flatfish species only eat a small amount of commercially important fish species and are not considered as important fish predators. Fish that eat large fish are mainly large cod and saithe, which also have almost all other fish in their diet. Elasmobranchs (e.g. *spurdog*) are also important top predators in the North Sea foodweb, but the abundance of most species is currently at a low level and data on their diet is scarce, so they have not been included in the model.

A very important feature is that due to a successful reduction in fishing mortality for many stocks, **natural mortality is becoming a dominant source of mortality in the North Sea**. This means that the stock dynamics are increasingly influenced by **natural processes** and not by fisheries only. Understanding the role of other non-fish top predators, such as seals and cetaceans, is also important, particularly since these predator populations are expected to increase further.

Figure 2. Overview of the important predators and prey in the North Sea SMS model foodweb.



Other fish include grey gurnard, North Sea and western horse mackerel, and starry ray. Seabirds include fulmar, gannet, great black-backed gull, guillemot, herring gull, kittiwake, puffin, and razorbill. Seals and porpoises include grey seal and harbour porpoise. An "Other food" pool with constant biomass is included in the model to represent all prey types that are found in the stomachs but that are not modeled explicitly (e.g., crustaceans, mollusks, other prey fish). The colour of the line indicates which predator the species is eaten by, the thickness of the line indicates the biomass removed in this interaction (average from 1963 to 2010).

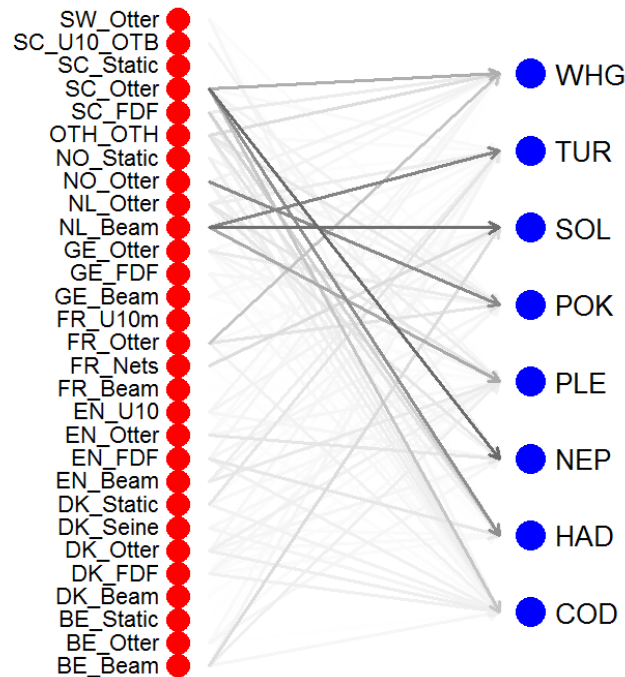
Source: (ICES, 2013), Figure 6.3.1.1

1.4.2. Technical interactions

The technical interactions among fishing units are mainly described and monitored in the ICES Working Group on Mixed Fisheries, WGMIXFISH. Data on catch and effort for the various types of fishing activities are collected annually. Distinction is made between the *fleet segment*, which describes a **group of vessels**, and the *métier*, which describes a type of activity (e.g. a given gear and mesh size targeting a given group of species). Typically, a vessel would belong to only **one fleet, but may engage in several métiers** over one year. These two concepts

provide a convenient medium layer between considering all fishing together without accounting for their diversity, and monitoring each vessel individually (Ulrich *et al.*, 2012). North Sea fisheries are **very diverse**, and often **very mixed** (i.e. métiers catch several different species). As the lowest level of vessels aggregation, ICES uses a segmentation by country (nine categories), gear type (four categories), vessel length class (four categories), and with additional provision for Fully Documented Fleets. This leads to a total number of **39 fleet segments**. These fleets engage in one to five different métiers (different mesh size) and/or areas (including North Sea, Skagerrak or Eastern Channel) each, resulting in **105 combinations of fleet*métier*area** targeting cod, haddock, whiting, saithe, plaice, sole and *Nephrops* (ICES, 2015c), and catching also a great diversity of other **bycatch**. These numerous combinations can naturally be aggregated into **fewer categories** for easing the display and the interpretation of results. The Figure 3 illustrates this diversity, emphasizing the number of target species caught by each fleet.

Figure 3. Technical interactions in the North Sea demersal fisheries, based on 2014 catches by fleet aggregated over vessel length classes. The colour of arrows is proportional to the share of total catches by species taken by each fleet.



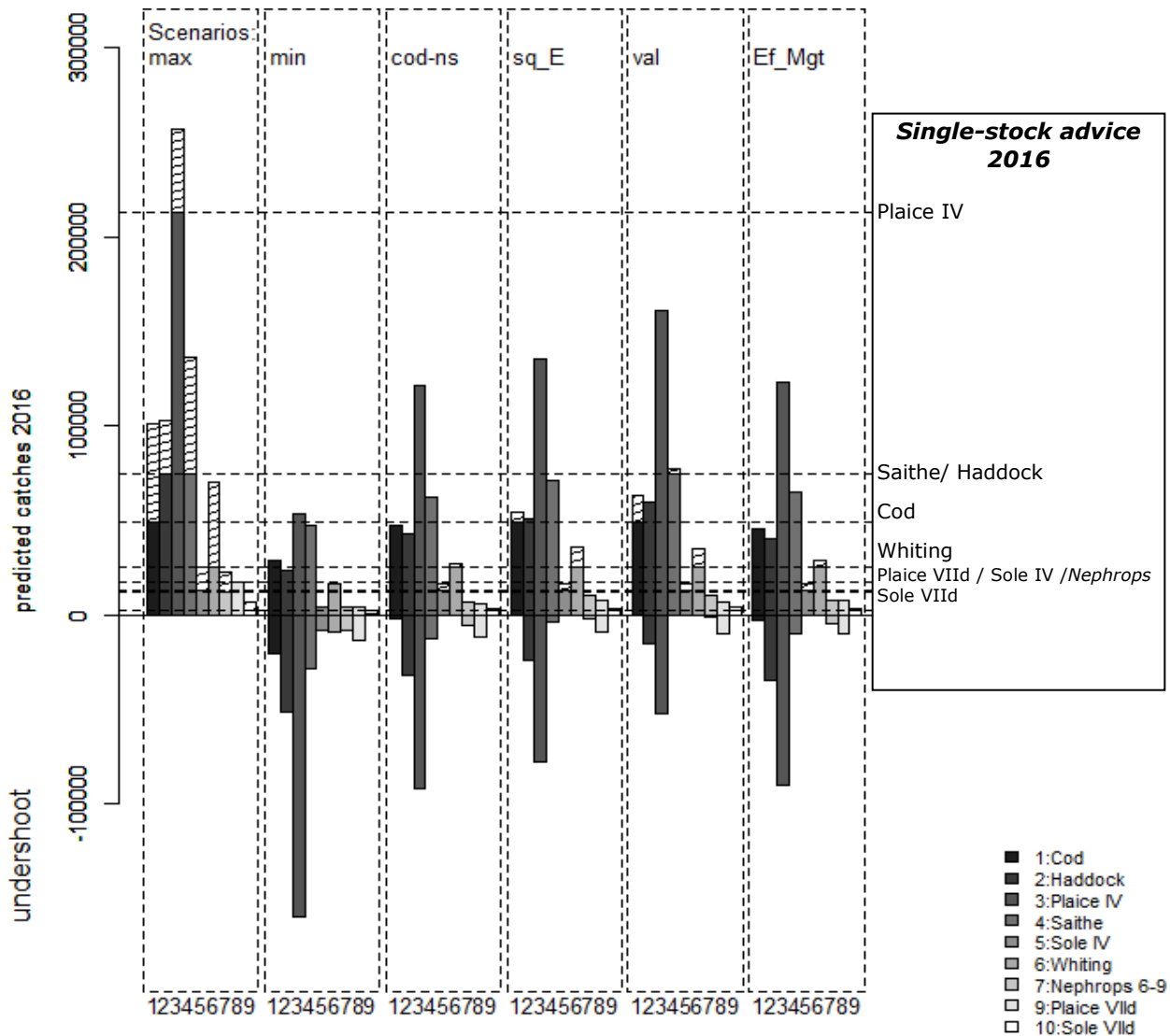
WHG: Whiting; TUR: Turbot; SOL: Sole; POK: Saithe; PLE: Plaice; NEP: *Nephrops*; HAD: Haddock; COD: Cod.

Source : DTU Aqua, (ICES, 2015c) data

The major impact of technical interactions is that they may **prevent** reaching **MSY for all stocks** at the **same time**, since the F_{MSY} for the different stocks correspond to different levels of fishing effort. Conceptually, this implies that the fleets may either be constrained by the stock with the smallest relative quota, the “**choke stock**”. The choke stock can be the least productive stock (which can be either a target e.g cod, sole or whiting or a bycatch e.g. turbot) or the stock with quota imbalance compared to historical right allocations (e.g. **hake**). The fleets would either **not be allowed to fully exploit the more productive ones**, or would exploit (and possibly discard) the choke stock above its F_{MSY} level in order to maximise the economic returns from the other stocks. This dilemma is the cornerstone of **all mixed-fisheries models** (see also section 3 Tor 2 below), and has been formalised by ICES since 2009 in the form of an annual advice on mixed-fisheries (Figure 4), which quantify the risk of

not achieving the single-stock management objectives because of the risks of **over quota** catches (ICES, 2015d; Ulrich *et al.*, 2011):

Figure 4. Standard plot of ICES mixed fisheries advice. Estimates of potential catches (in tonnes) for 2016 by stock and by scenario. overshoot (hatched) and undershoot (below zero).



Horizontal lines correspond to the single-stock catch advice for 2016. Bars below the value of zero show undershoot (compared to single-stock advice) where catches are predicted to be lower when applying the scenario. Hatched columns represent catches in overshoot of the single-stock advice

Source: (ICES, 2015d), Figure 6.2.2.2.1

Since the beginning of such advice in 2009, **cod** has repeatedly been estimated to be the most **limiting** target stock in the North Sea **demersal fisheries** (hake is not included in these considerations), until last year. In 2015, ICES estimated for the first time that it had recovered enough to be managed in more balance with the other stocks, while the most **limiting target stocks** turned out to be **whiting and sole** (ICES, 2015d).

1.4.3. Other ecosystem considerations

Beyond the **predator-prey** and the technical interactions, other aspects that may affect the achievement of F_{MSY} will be the **constraints** imposed by the Marine Strategy Framework Directive (MSFD), with the need to achieve **Good Environmental Status (GES)** in EU Waters. There are important activities going on regarding this topic, closely involving ICES and EU Member States. Of particular importance for fisheries management is the consideration of **bycatch species**. There are a lot of developments ongoing into this topic (see also (ICES, 2015e)). The impact of demersal fisheries on the seafloor and on fish habitats is another important issue. As these discussions are still very much in progress by the time of writing this report, they are not further detailed here, but this should be kept in mind in the **policy considerations**. ICES has recently published the first integrated ecosystem **overviews for several ecoregions**, including the North Sea, and these provide a useful source of knowledge for ecosystem-based marine management (ICES, 2016).

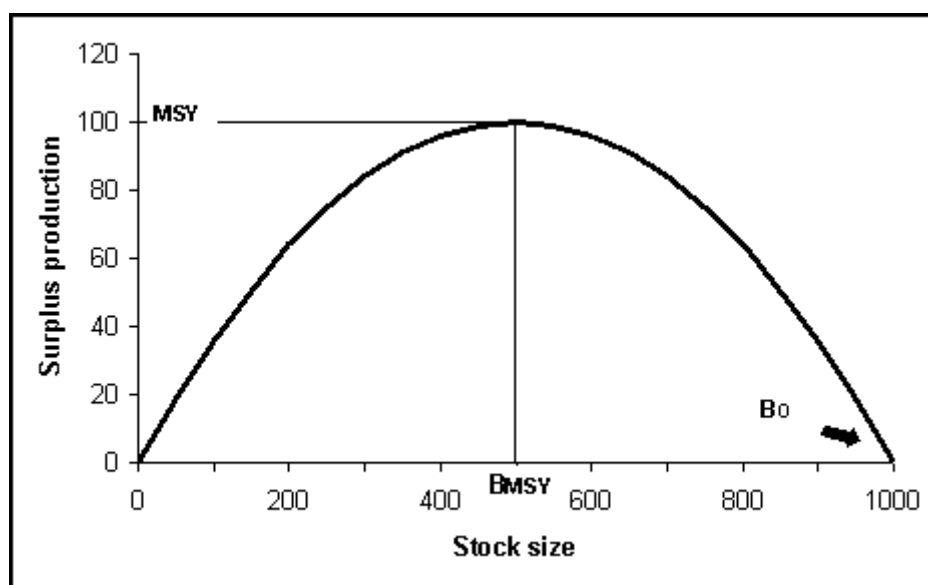
2. Current state of MSY modelling in the region

KEY FINDINGS

- The **productivity** and growth potential of the different stocks **is variable over time** and partly influenced by large scale climatic processes.
- It is difficult to define a unique and constant F_{MSY} for each stock, and to manage fisheries after this. **Not all stocks may be at single-species F_{MSY} at the same time and for the same level of fishing effort.**
- Ecoregion-wide MSY beyond the single-stock context **is difficult to define** as there is **no unique definition and quantification** of the concepts of Yield, of Sustainability and of Maximum
- **There is no unique target** that can satisfy all objectives and constraints at the same time, **and trade-offs are necessary**
- **Defining North Sea-wide MSY in weight or in value leads to opposite directions** due to the biological interactions: Maximising MSY in weight would imply high fishing mortality and low biomass of demersal predator fish (such as cod and saithe), to **secure large populations of small pelagic prey fish** (such as herring and sprat) that can be fished intensely. At contrary, maximising MSY in value would imply reducing the pelagic fisheries, to **secure food for larger stocks of high-valued demersal predator species.**
- **Using Maximum Economic Yield (MEY)** as a target would achieve a lot of objectives, such as low ecosystem impact and high profitability of the fisheries. But **MEY is typically achieved at fishing mortality lower than F_{MSY} , implying fewer vessels and lower employment** in fisheries than at present.
- For many stocks **a range of fishing mortalities** around F_{MSY} could achieve high, sustainable and precautionary yield in the vicinity of the maximum estimated.
- Defining **F_{MSY} as an area** with a range rather than a point estimate provides a frame that can account for the variability in the ecosystem and integrate some other ecological, economic, social and/or institutional objectives, but this implies **making trade-offs.**

2.1. The history of MSY in the North Sea

The North Sea has traditionally been the most studied and modelled area in European fisheries. Earliest records on the idea of a Maximum Sustainable Yield are found in the late XIX century, when hypotheses started developing to explain the observed variability of North Sea fish stocks (Degnbol, 2015). This question triggered the creation of the first global organisation for marine science, The International Council for the Exploration of the Sea (**ICES**) in 1902. Later, the variability of year-class strengths was hypothesised for the first time in the Northern North Sea and Norwegian waters (Hjort, 1914), leading to the **concept of “optimum catch”** in 1933. It is also with North Sea stocks that Graham et al (1935) first established the famous equilibrium yield curve with a MSY top (later popularised by Gordon and Scheafer, Figure 5), and that (Beverton and Holt, 1957) quantified and operationalised the concept in an **age-structured approach accounting for the annual variability of growth and productivity.** In the same time, similar developments took place on the East Coast of the USA, so most of the early development of modern quantitative fisheries science has been fostered in these two areas.

Figure 5: The Gordon-Scheafer MSY yield curve from equilibrium biomass model

Source: FAO (Cochrane, 2002)

Since the time of these early pioneers in fisheries science, continued development in fisheries modelling has occurred on the North Sea fish stocks, which are now among the **most studied in the world**. The quantity and quality of fisheries data and models available is high, **both at the single-stock level and at the ecosystem and regional scale**. We review separately the state of the art regarding MSY modelling at these two scales.

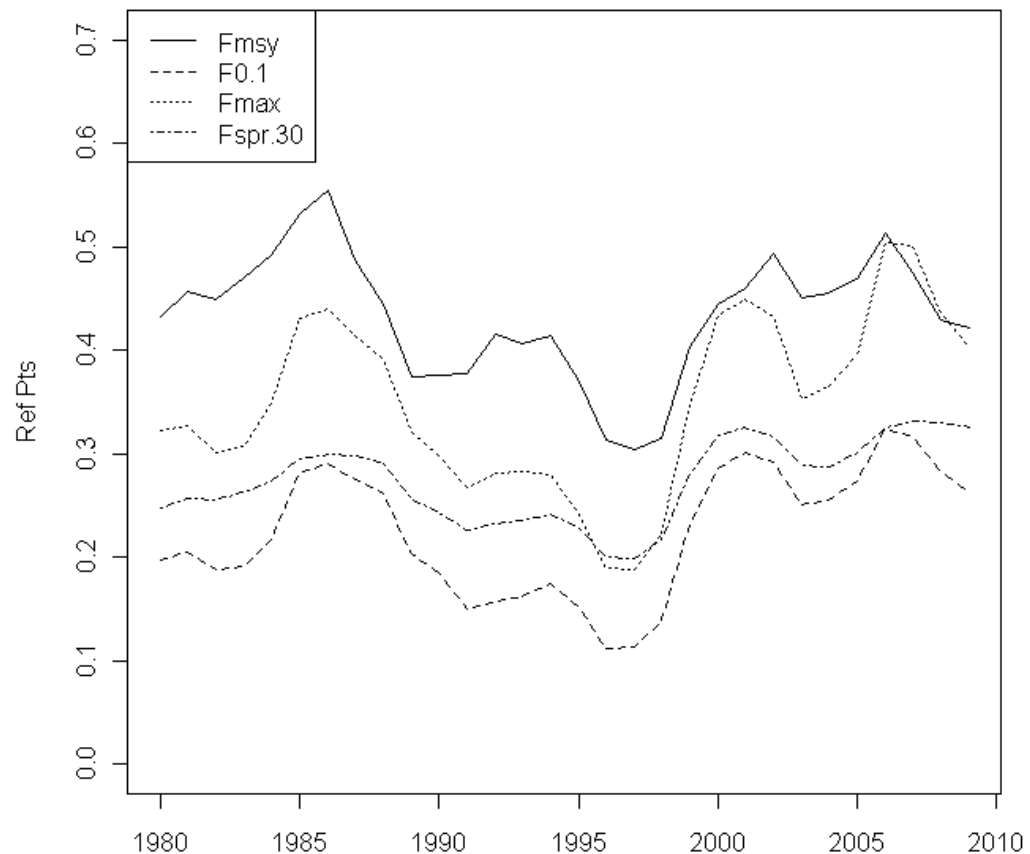
2.2. Single-stock F_{MSY}

2.2.1. Stocks with an analytical assessment

2.2.1.1. F_{MSY} : point estimate, variability and uncertainty

Considering the most **recent** history only, the work to identify F_{MSY} **started in 2010** for most **ICES stocks** (ICES, 2010a, 2010b). At that time, the variability of F_{MSY} over time, due to the annual fluctuations of the basic productivity, growth and selectivity parameters was already highlighted. This is illustrated for haddock on Figure 6, but similar fluctuations were observed for most stocks. This revived the historical long-lasting debate regarding the **inadequacy** of the equilibrium **MSY concept in a dynamic ecosystem** where stocks fluctuate and interact (Larkin, 1977).

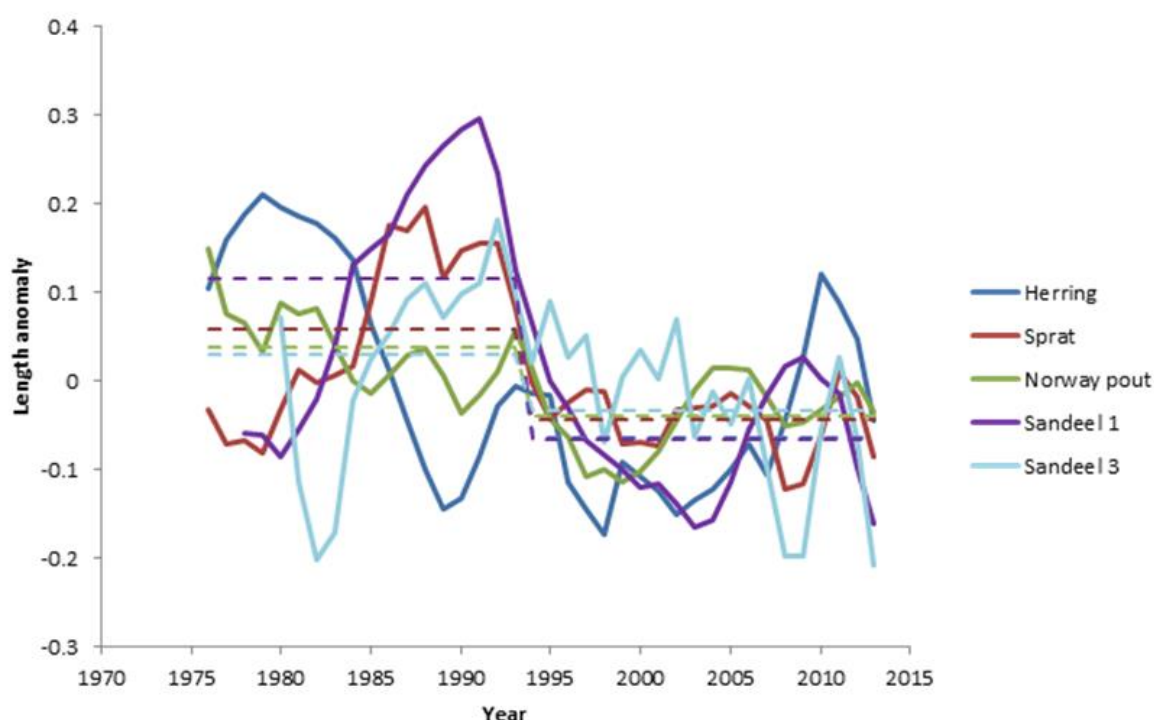
Figure 6. Haddock in Subarea IV and Division IIIa. Retrospective estimates of fishing mortality reference points.



Source: (ICES, 2010a)

Some progresses have been achieved in investigating the **causes of the variability of growth and productivity over time**, especially when trends are observed beyond the annual fluctuations. In particular, the role of the **increasing temperature** has been often advocated, as this can affect many processes. (Baudron *et al.*, 2014) showed that six out of **eight commercial fish species** in the North Sea underwent concomitant **growth reductions**, and this coincided with a 1–2 °C increase in water temperature. Smaller body sizes decreased the yield-per-recruit of these stocks by an average of 23%. The **recruitment** success of North Sea cod may also have decreased because of **reduced plankton availability** for the early life stages in warming waters (Beaugrand *et al.*, 2003; Nicolas *et al.*, 2014). Similarly, (Clausen *et al.*, 2016) investigated the productivity of **all small pelagic species** in the North Sea, showing a drop in both growth and recruitment since the early nineties (Figure 7). This correlates to some extent with **the shift** in the composition of plankton community although the direct causal effect yet needs to be concluded. **The effect is clear**, though; **the MSY and precautionary reference points are different between the high and low productivity period** in the North Sea. Changes in productivity can also be linked to e.g. changes in predation (Kempf *et al.*, 2009) or fisheries-induced evolution (Marty *et al.*, 2014).

Figure 7. Solid lines: Time trends in anomalies in fish stock length at age (for age 2 and over), i.e. the relative deviation in length from mean for the time series by age for any given year. Broken lines: Mean before and after 1993.

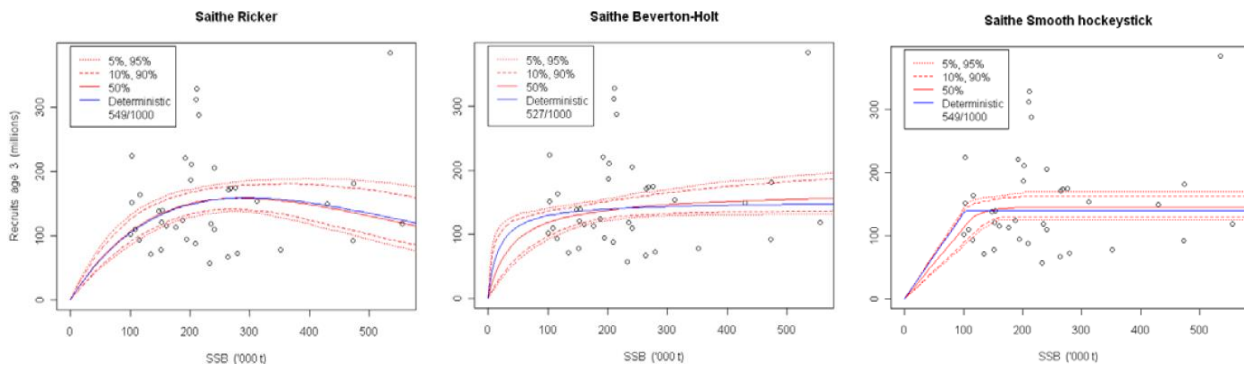


Source
:(Clausen *et al.*, 2016)

But in most cases, the **variability of the system** cannot be fully explained and more importantly, **cannot be predicted** for the future. Instead, the scientific efforts have rather focused on the best way to integrate this variability as a key input to MSY modelling. Since 2010 the statistical analyses have thus been **refined**, in order to achieve better consistency across the **different methods** available to **estimate F_{MSY}** and to build a generic framework across stocks. In particular, much focus has been given to the handling of the uncertainty **linked to the relationship (SRR) between spawning stock biomass (SSB, the parental biomass) and the recruitment (number of offsprings)**. F_{MSY} is primarily sensitive to whereas it is assumed that the SRR is **rather flat** (above a given level of biomass, recruitment fluctuates around average without trends, “Hockey-Stick” shape), **rather increasing** (higher biomass gives higher average recruitment, asymptotic “Beverton and Holt” shape, leading to a lower F_{MSY}) **or rather dome-shaped** (above a given level of biomass, the **average recruitment** might decrease due to density-dependent effects, i.e. negative effects that occurs when the density (numbers per unit of area) of animals increase: typically **increased predation** including cannibalism and/or food or habitat shortage; “Ricker” shape, leading to a higher F_{MSY}) (Figure 8). In most cases though, the time series of observed recruitment does not clearly follow any of those three choices, but is a more scattered cloud of points.

To account for this uncertainty, a probabilistic and stochastic framework was developed including all **three options**. In addition, attention was paid to include **precautionarity** in this framework, so that the risk of **falling below B_{lim} should be low** (<5%, with the corresponding fishing mortality noted $FP_{0.05}$) when fishing at F_{MSY} over a long period of time (Figure 9, red line in the right panel) This work culminated in an ICES Workshop in late 2014, which applied this framework to most stocks in the Baltic Sea and North Sea and provided consistent F_{MSY} and precautionary $FP_{0.05}$ estimates (ICES, 2015f, 2015g).

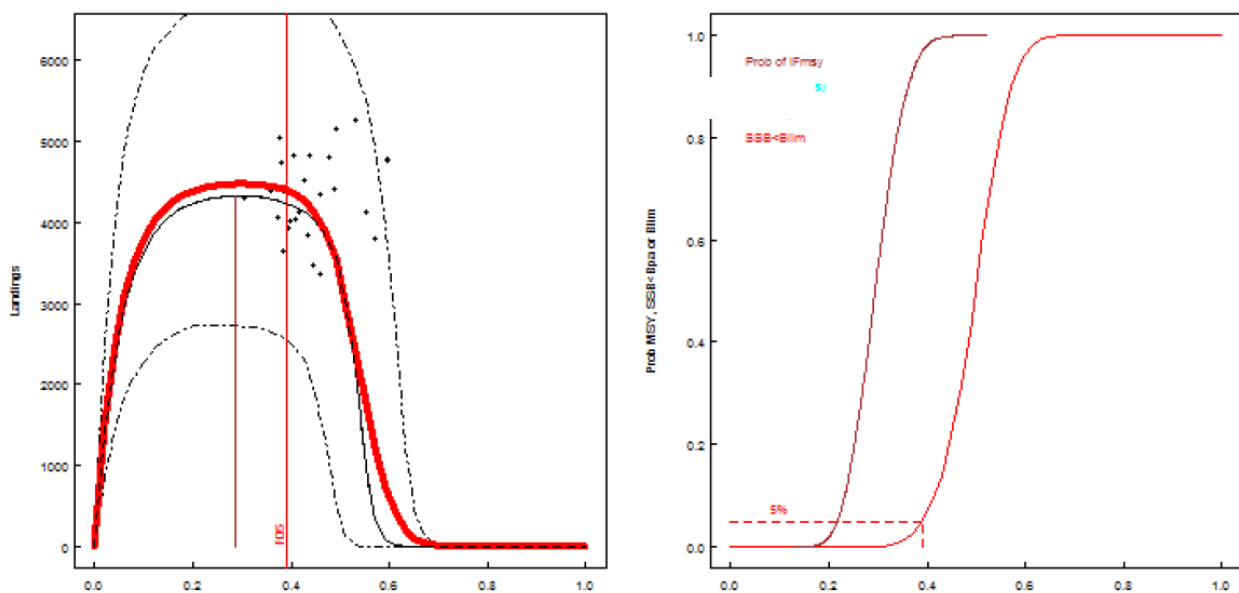
Figure 8. Different stock-recruitment relationships fitted to North Sea saithe.



Source : (ICES, 2010a), figure 11.9.1

The outcomes of this work have shown clearly and consistently that **given the annual fluctuations in growth, productivity and selectivity, it is often difficult to provide a single value of F_{MSY}** . The estimated long-term Maximum Yield can be obtained with a range of fishing mortalities, depending of the combination of these parameters. Taking Eastern Channel sole as an example below (Figure 9), we can see that different long-term yields can be obtained for any given level of fishing mortality (between dotted lines on left panel). Turning this around, this implies that the average highest yields can also be obtained with several F values, here between 0.2 and 0.4 (red line left panel, plotted correspondingly as a probability distribution in the brown line, right panel).

Figure 9. Summary plot for Sole VIIId. Left: historic values (dots), mean (solid red), median (solid black) and 90% intervals (dotted black) landings for exploitation at fixed values of F . Right: probability of $SSB < B_{lim}$ (red, with $FP.05$ shown with the dotted line) and the cumulative distribution of F_{MSY} (brown).



Source : (ICES, 2015g), Figure 6.16.4

This means that the **F_{MSY} point-estimate** that is finally produced as the key result of this work (ICES, 2015f) is an **average** (median) across many plausible future developments in the stock, based on historical observations of both high and low productivity periods. This value could be kept constant for some years, provided that the current productivity does not vary outside the assumptions made on the basis of these historical observations.

Another **important finding** of this study was the observation that for most **short-lived and small fish, the F_{MSY} is very close to the precautionary FP.05**, while a number of **large fish** (able to grow larger than 60 cm) stocks can potentially **sustain** high and precautionary yields across **a range of fishing mortality** (ICES, 2015g). For these stocks, long-term fishing at F values which are slightly higher or lower than the average F_{MSY} can deliver average yield quite close to the estimated maximum. For such F values higher than F_{MSY} , this implies average **biomass levels slightly lower than at F_{MSY}** , but with a probability of at least 95% of staying above B_{lim} .

This framework was also used to derive MSY ranges, see chapter 2.3.3 below.

2.2.2. Stocks without an analytical assessment

For stocks without an analytical assessment (ICES DLS Category 3 to 6), ICES has so far not estimated a MSY based target, nor an F_{MSY} range. **The advice for these stocks is currently based on the precautionary approach**. ICES has tested methods to derive reference points and they have already been tested on western waters stocks (ICES, 2015h). The other stocks, including the North Sea ones will follow from 2017. In addition, a DGMARE tender (number MARE/2014/44) has started in early 2016 to develop management strategies for stocks without analytical assessment. The North Sea is one of the case studies covered, and major progresses are expected to be achieved between 2016 and 2018.

2.3. Multiple stocks / Ecoregion-wide MSY

2.3.1. Generic issues in defining MSY beyond the single-stock concept

The concept of MSY in a wider North Sea **ecosystem and/or mixed-fisheries regional approach** is much more **complex**. There are many models and many studies that have investigated this concept from different angles, but none of them has yet emerged as a consensual approach directly used to establish official management targets. Issues in identifying **MSY beyond the single-stock concept** are both a matter of **definition** and a matter of **quantification**.

First, the basic concept of **Maximum Sustainable Yield** becomes **fuzzier** and more difficult to agree on **in an ecoregion** context. Each of the three words must be defined: **What means Yield** (e.g. yield of all stocks, or of main commercial stocks? Yield in tonnes or in value? Or Profit, as in Australia, which uses MEY as the primary policy objective)? **What means Maximum** when stocks and fleets fluctuate every year, and how to define “on average”? **What means Sustainable**, and sustainable for what and for who, when sustainability can be defined out of **several pillars and scales** (Charles, 1994; Hilborn *et al.*, 2015)? Defining these terms is not a question for scientists alone, as there is no single and straight answer to these questions. Clearly, they require legitimate choices from managers and stakeholders as well.

Second, once defined, these terms must be **quantified**. That is largely a task for scientists to do. But as the marine ecosystems and the fisheries that exploit them are so complex and dynamic, no model is able to encompass in a single frame all ecological and human processes and how they impact each other. The models that try to incorporate as many of these processes as possible (e.g. Atlantis modelling framework, (Fulton *et al.*, 2011a) are based on many **modelling** assumptions and require a large number of parameters to be quantified. They are useful for identifying broad patterns but are not so well suited for the daily management of fisheries.

Rather, models of medium complexity have developed over time to investigate specific subsets of these processes, resulting in a situation where **several intermediate models** may be available for addressing a given question. These different models will likely provide **different MSY outcomes**, depending on which **processes** are **integrated** and how. Scientists are therefore able to provide a given answer for a given question (e.g. *“using this given model which includes these given processes and assumptions, the maximum sustainable yield defined in this given unit for this given set of stocks and for this given time frame is XXX”*), but they cannot provide a **single answer** on an overall ecosystem-based MSY that would be unique, would **encompass all processes** and would be **constant** over time.

Nevertheless, a common feature of these models is that they all focus on **highlighting some trade-offs between various objectives and various constraints**. For example, if predator-prey relationships are considered, any increase in the biomass of predators will **cost** yield from **prey stocks**; if **mixed-fisheries** are considered, a fishery having to stop when the first quota is exhausted will mean **losing yield from other species**; if social aspects are considered, more profitable fishery may come at the cost **lower employment**. Scientists will therefore use these models (individually or in combination) to inform managers and stakeholders on **which processes** and which sources of uncertainty **influence** the most **the identification of objectives** and their **achievement**; **which trade-offs** are the most **crucial** to consider; and **which options** are the most **robust** and the most **sustainable** according to **different criteria**.

Another important aspect to consider is the **variability** over time. The scientific models represent the best available knowledge **at a time**, and are based on the current situation. Managers and stakeholders must realise that most likely, MSY estimates will have to be **regularly** updated, following the prevalent conditions of ecosystem productivity and fisheries selectivity, and following also the development of **new knowledge** and **new policy objectives**.

Finally, **the role of science** is to **provide knowledge** on trade-offs and **risks** according to given criteria, but not to decide which criteria are *decisive* to policy-makers and society. It is the role of the political arena to make final decisions on where to go within different sustainable options.

An overview of the quantification of MSY in the North Sea is given below. This is largely based on the outcomes of the research project EU FP7 MYFISH referred to in section 1.1. This project has investigated how to integrate these interactions into ecosystem-wide MSY approaches in much detail. But a few other models are also available.

2.3.2. Quantitative ecoregion-wide North Sea MSY

This paragraph is the key outcome of the FP7 project MYFISH, summarised in (Kempf et al., in press)⁶. Most of the paragraph is extracted from this scientific paper, which reviews both the **various modelling** approaches undertaken and how their outcomes have been perceived by a number of key stakeholders and policy makers through a suite of **consultations and workshops** between 2012 and 2014. Some of the results have been updated in this present review with the latest results available in December 2015.

A **first exercise** aimed to define a number of potential variants of MSY objectives, and **three definitions** were retained: Maximum Sustainable Yield in landed weight (**MSYw**); Maximum Sustainable Yield in landed value (**MSYv**); Maximum Economic Yield in net present value

⁶ See also the corresponding presentation at <http://myfishproject.eu/images/MYFISH/symposium/Talks/Day2/AlexanderKempf.pdf>

(MEY). A **second exercise** aimed to quantify and compare these three variants, across **three models** incorporating various types of biological and/or technical interactions; **A third exercise** aimed to identify some constraints that would prevent the achievement of these objectives. Constraints would be **undesirable states** of either the ecosystem (e.g. too high bycatch levels of some sensitive or protected species, or incompatibility with MSFD GES indicators) or of the fishery (e.g. poor profitability or employment levels, low equity etc).

The outcomes of these exercises have been summarised under the form of **three graphical Decision Support Tables (DSTs)**, one for each model. The DSTs represent the main trade-offs across the various MSY objectives, and between objectives and constraints.

As explained above, these DSTs are the outcomes of **different models**, focusing on different issues and types of fisheries in different areas of the North Sea. They are thus not entirely comparable with each other. They shall rather be used individually for comparing trade-offs across scenarios within a given modelling approach. The DST tables are not reproduced here but are displayed in the MYFISH newsletter 3 in a synthetic version⁷.

2.3.2.1. MSY accounting for species predator-prey interactions (DST1)

This work is a direct follow up of initial considerations presented in (ICES, 2013) advice and described in chapter 1.4.1.

This first DST investigated the MSY trade-offs linked to **biological interactions**, where the biomass of a stock is dependent of the biomass of other stocks eating it. **Cod and saithe** are **top predators** feeding on all species, while herring, sprat, **Norway pout and sandeel** are only **preys** and do not eat other fish. **Whiting and haddock** are intermediate. **Small pelagic fish** produce **high tonnages** with **low monetary** unit value while **demersal fish** produce **smaller volumes** of **higher-valued** fish.

The main result of this analysis was that MSYw and MSYv pull the system into opposed directions. The absolute long-term **Maximum Yield (MSYw)** translated into a **higher fishing mortality of predators** compared to single species F_{MSY} estimates, in order to provide the highest tonnage from **intense fishing of the pelagic and industrial species**. Conversely, **Maximising Yield in value (MSYv)** suggested **reducing the fishing of these smaller species** to maintain food for the more valuable species. Similar results had also been obtained by other models including EwE (Mackinson *et al.*, 2009) and size-spectrum models (Blanchard *et al.*, 2014; Jacobsen *et al.*, 2013).

A trade-off between these two extremes is difficult to estimate mathematically, as there is no obvious objective to maximize. Adding **sustainability** constraints aiming to maintain each stock above a minimal **biomass level (Blim or Bpa)** reduced the span of the potential fishing mortalities, and reduced also the multispecies level of maximum yield in tonnes and in value. There remains nevertheless a **probability that not all stocks can be maintained** above precautionary **single-species biomass reference points simultaneously**. In particular, **whiting may suffer** from high juvenile predation pressure by grey gurnard and by a recovery of the cod stock.

⁷ http://myfishproject.eu/images/MYFISH/Media/Newsletter/MYFISH_Newsletter_Issue3.pdf

Ultimately, the total yield in tonnes and in value of the entire **North Sea fishery** does **not vary** much across a wide **range of combinations** of single-stock fishing mortality levels (potentially less than **15%** difference in total yield and less than **10%** in total value across the various scenarios of objectives and constraints, Vinther et al., MYFISH deliverable 3.2). It is therefore possible to achieve a total yield very close to the maximum (a “**Pretty Good Yield**”) without jeopardizing either the biomass or the fishery of any of the stocks (to the exception of **whiting** for which the outcomes remain uncertain).

2.3.2.2. *MSY accounting for mixed-fisheries technical interactions (DST2)*

This second DST focused on the **economic impact** of MSY on the fishing fleets from the different **North Sea** countries, and is performed using the model FishRent (Salz *et al.*, 2011). It was analyzed whether better profitability could be achieved for identical levels of fishing mortality by stock (point estimate F_{MSY}) by changing the distribution of national quota (fixed share of the TAC by stock) across fleets within a country.

The model was parameterized on data up to **2013**, where the cod stock was still very low compared to the other **roundfish stocks and the cod** TAC was very limiting. There it was shown that countries’ quotas could be better utilized, and the fleets would be more profitable if **quotas would be freely swapped**. It was also shown important trade-offs in terms of employment and fishing effort if fishing costs are accounted for, illustrating that pursuing a MEY objective maximizing profit would imply a very different configuration of the fleets, moving from a situation with many vessels with low profitability to a situation with few but highly profitable vessels (Hoff and Frost, MYFISH deliverable 3.2)

2.3.2.3. *MSY accounting for technical interactions and Good environmental status (GES) (DST3)*

This third DST focused on the linkages between MSY and selected MSFD GES indicators for the flatfish and brown shrimp beam trawl fisheries in the **Southern North Sea**. In particular, also the impact on sensitive bycatch species such as **turbot** and **elasmobranchs** was investigated. The DST was obtained through a combination of the ecosystem model Ecopath with Ecosim (EwE, (Christensen and Walters, 2004)) and the spatial economic model Simfish (Bartelings et al., submitted).

An important outcome from this analysis was that **MSYw is not optimal from an economic and conservation point of view**. It led to a substantial loss in profit and risks the sustainable exploitation of bycatch species. On the other hand, MEY leads to lower fishing effort, which has a positive impact on GES indicators, but at high social cost in the form of much lower employment.

2.3.2.4. *Summary of MSY outcomes and some managers’ reflections*

These three DSTs studies have highlighted important **trade-offs** across **multiple objectives** because of **biological** and **technical** interactions as well as social **constraints**. The results were presented and discussed with several managers and stakeholders across the North Sea (Kempf et al., submitted). Especially trade-offs related to biological interactions were identified by managers as being an issue of high potential conflict, because of the implications for **demersal vs. pelagic fleets**. It was also noted that the **current definition of MSY** “to maximise the yield in weight from a stock or community” may lead to undesirable outcomes such as loss in profit and conflicts with **environmental constraints**. MEY seems to be a more appropriate concept to cover wider objectives, but would come at the cost of lower employment.

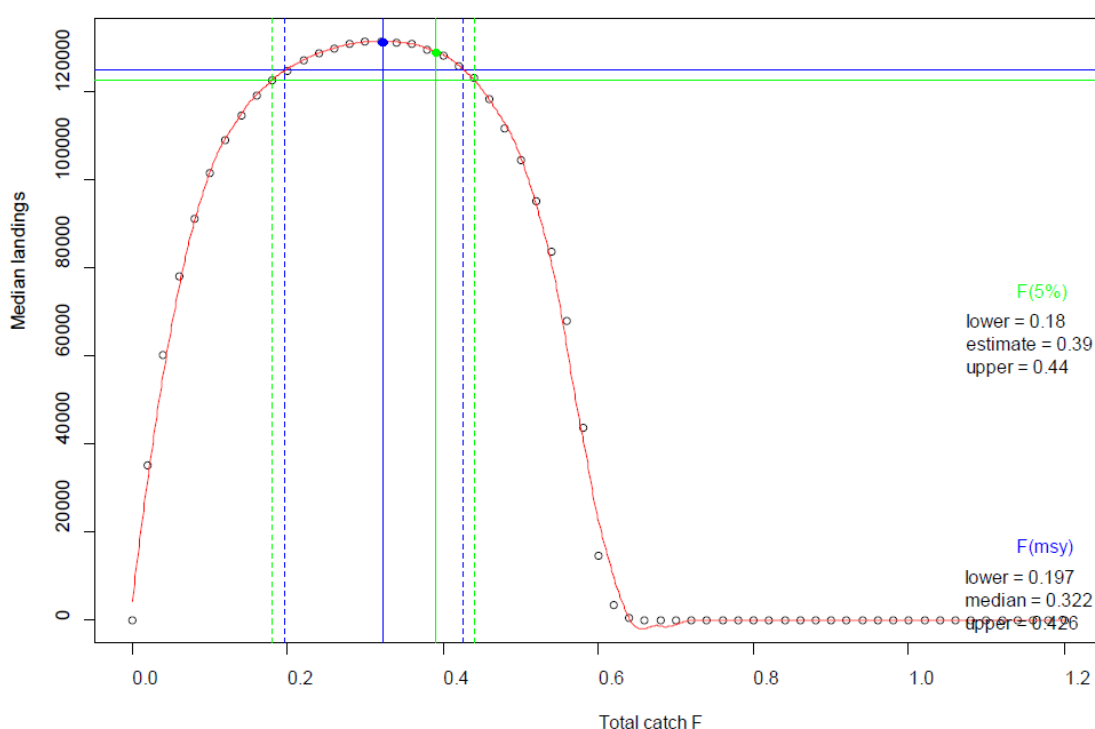
Learning on trade-offs led to the idea that a “Pretty good yield concept” may be more suitable instead of trying to define and reach the absolute maximum.

2.3.3. F_{MSY} ranges

In parallel to the work developed in MYFISH, the EU has also been forced to discuss these issues from a **policy point of view**, in order to implement the CFP objectives of MSY and **mixed-fisheries management plans** (European Parliament and Council of the European Union, 2013). A task force (EU, 2014) comprising the three main EU Institutions (EU Commission, EU Parliament and EU Council of Fisheries Ministers) suggested to use **F_{MSY} ranges as flexible targets for the regional management plans rather than prescriptive Harvest Control Rules** (STECF 2015a), de-facto considering MSY as a desirable multi-dimensional area rather than a point estimate. The idea started thus to emerge that the MSY concept could be extended into a multidimensional area, the “Pretty Good Yield” (PGY) area (as named by (Hilborn, 2010)). This idea means that a part of the maximum yield could be traded off against the achievement of the other objectives, in particular with regards to mixed-fisheries conflicts in the frame of regional management plans and the landing obligation.

ICES was thus tasked by the EU Commission to identify a range of precautionary F values that would deliver a PGY, and a threshold of **at least 95%** of the maximum estimated **average long-term yield in a single-stock approach** was chosen. The boundaries of this area are the so-called F_{MSY} ranges (ICES, 2015f) (Figure 10).

Figure 10. Median landings yield curve with estimated reference points for North Sea saithe, with fixed F exploitation from $F=0$ to 1.2. Blue lines: median F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: precautionary $FP.05$ estimate (solid) and range at 95% of yield at $FP.05$ (dotted)



Source: (ICES, 2015g), Figure 6.12.2

In 2015, many of the North Sea stocks were exploited at levels within the estimated range (Table 2)

Table 2. F_{MSY} point estimate and range for the main North Sea demersal stocks, and fishing mortality in 2014.

STOCK	ICES STOCK NAME	F_{MSY}	F_{upper}	F_{lower}	F_{2014}
cod-347d	Cod in Subarea IV (North Sea) and Divisions VIId (Eastern Channel) and IIIa West (Skagerrak)	0.33	0.49	0.22	0.39
had-346a	Haddock in Subarea IV and Divisions VIa and IIIa West (North Sea, West of Scotland, Skagerrak)	0.37	0.52	0.25	0.24
nep-3-4	<i>Nephrops</i> in Division IIIa	0.079	0.079	0.056	0.030
nep-6	<i>Nephrops</i> in Farn Deep (FU 6)	0.081	0.081	0.07	0.13
nep-7	<i>Nephrops</i> in Fladen Ground (FU 7)	0.075	0.075	0.066	0.035
nep-8	<i>Nephrops</i> in Firth of Forth (FU 8)	0.163	0.163	0.106	0.291
nep-9	<i>Nephrops</i> in Moray Firth (FU 9)	0.118	0.118	0.091	0.147
ple-eche	Plaice in Division VIId (Eastern Channel)	0.25	0.34	0.18	0.11
ple-nsea	Plaice in Subarea IV (North Sea)	0.19	0.27	0.13	0.18
sai-3a46	Saithe in Subarea IV (North Sea), Division IIIa (Skagerrak), and Subarea VI (West of Scotland and Rockall)	0.32	0.43	0.2	0.3
sol-eche	Sole in Division VIId (Eastern Channel)	0.3	0.41	0.16	0.55
sol-nsea	Sole in Subarea IV (North Sea)	0.2	0.37	0.11	0.25

Values highlighted in green are below F_{MSY} , in orange are values between F_{MSY} and $MSY F_{upper}$, and in red are above $MSY F_{upper}$.

There are however many discussions whether F_{upper} is truly an acceptable MSY reference point. ICES underlines that using **ranges and deciding upon the PGY threshold** (here 95%) is a **policy decision** that can help balance trade-offs, not a scientific one. (ICES, 2015f) noted the following: "In a single-species context fishing above F_{MSY} implies reduced stock biomass and this may be substantial where F_{upper} is much higher than F_{MSY} . So in utilizing F_{MSY} ranges there are more advantages to **fishing between F_{MSY} and F_{lower}** than between **F_{MSY} and F_{upper}** .

With higher fishing mortalities the following occurs:

- A need for increased fishing effort;
- Higher dependence of stock and yield on **recruiting** year classes and increased variability on catch opportunities;
- The size of the fish in the stock and the catch will be smaller on average;
- Greater probability of **SSB being less than MSY $B_{trigger}$** , implying that advised catches would have to be reduced more often according to the sliding rule used in ICES advice;
- A lower probability of density-dependent effects such as reduced growth or increased cannibalism.

For some **mixed fisheries** it may be difficult to reconcile the F_s on different stocks. An approach for maximizing long-term yield could be to attempt to reconcile F on a **mixed fishery using F_s between F_{lower} and F_{MSY}** . If this cannot be accomplished, F between F_{MSY} and F_{upper} could also be used in the short term. However, using $F > F_{MSY}$ for the same stock in the long term implies that there are **structural changes** required in the fishery to avoid the consequences listed above."

2.4. Summary on MSY modelling in the North Sea

In summary, the state of the art of the **modelling of MSY** in the North Sea is made both of an old history with long-lasting prospective and knowledge, and of a very recent and prolific scientific activity which has opened, and is still opening, **new insights on this old concept**. These look for **pragmatic and robust management approaches** to the intrinsic **issues of variability and definition**. The story is not fully matured yet, and new questions are still likely to emerge from these current findings over the next few years. But this can be summarised as follows:

2.4.1. An appealing old concept but with well-known issues

The problems with the definition and performance of **MSY targets** in fisheries are well documented, even for a single-species if there are natural fluctuations in the resource (Mace, 2001). Where there are **multiple interacting species** and/or multiple objectives it becomes even more difficult to evaluate the many trade-offs that inevitably occur and to establish any overall optimised outcome. These issues are not new, and Larkin (1977) already stated that single species MSY cannot be achieved simultaneously for all species within an ecosystem when biological interactions (**such as predator-prey relationships**) are considered. It is also well understood that because of mixed-fisheries interactions, not all stocks can reach MSY at the same pace, and managing fisheries according to the least productive stock(s) can lead to the under exploitation of other stocks (Hilborn *et al.*, 2015; ICES, 2015d).

The **modelling** capacities have improved greatly since the seventies, and numerous advanced scientific studies have been performed in the last ten years. Nevertheless, more complex and holistic approaches haven't solved these basic questions, and the accumulated evidence demonstrates clearly the inherent **difficulties** for **managers and scientists** to **(i) agree** on a single and simple definition of MSY in an extended and dynamic ecosystem context, **(ii) translate** this into robust and constant single-stock point estimate F_{MSY} and **(iii) manage** variable and complex fisheries towards these objectives.

These difficulties will not disappear, as they relate to the **intrinsic characteristics** of the **marine ecosystems and fisheries**. They will neither be solved by additional scientific modelling. The natural fluctuations of productivity and the multiplicity of ecological, economic, social and institutional objectives call for the acceptance of the needs to making **trade-offs**. One pragmatic approach forward would be to give more importance to avoiding **risks of adverse outcomes** than to optimising exactly the exploitation patterns across a given set of criteria to be defined (Degnbol, 2015; Hilborn *et al.*, 2015). In this sense, the **MSY objective** is still appealing in spite of the concerns summarised above (Mace, 2001; Patrick and Link, 2015). It induces higher yields, better ecosystem status and higher profitability than the previous European fisheries management frameworks; Being formulated more explicitly in the **2013 CFP** than in any previous CFP, MSY should ensure that the fishing mortality for European stocks is maintained in **the future at levels significantly below those observed in the past**. We argue thus that the **MSY** concept needs **adaptation**, not wholesale replacement (Kempf *et al.*, submitted).

2.4.2. Recent insights on the meaning of MSY in an ecosystem context: trade-offs and constraints

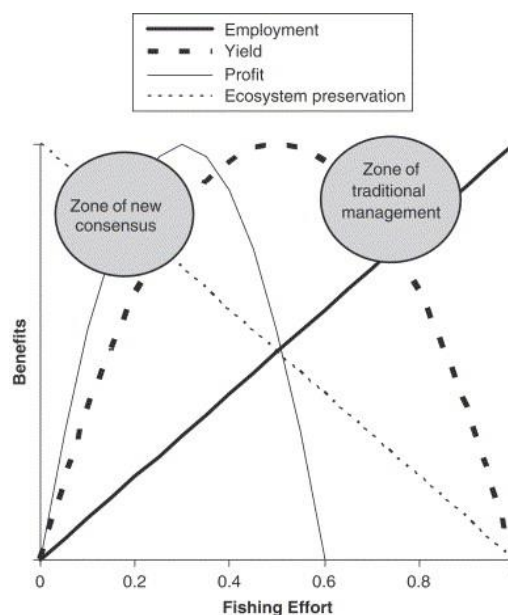
During the EU FP7 MYFISH project, **different definitions and quantifications** of MSY have been explored for the North Sea, considering or not the **predator-prey** relationships between species, the **technical interactions** between fleets, and **some ecological side-effects** on non-target species. These are three important aspects to take into account when considering

MSY beyond its narrow single-stock definition. Although performed with different models and with different focus, the outcomes of these three independent analyses tell similar stories:

The first main outcome is that total long-term Yield of the entire North Sea fishery varies fairly little across many different combinations of fishing mortalities for the different stocks. This outcome has two major implications. **(i)** because of the interactions, **the North Sea-wide MSY is not necessarily the same** as the sum of the MSY of the **individual stocks**, and is not necessarily achieved with the same level of fishing mortality as if fishing at the F_{MSY} point estimate for each stock individually. **(ii)** **not all combinations** of fishing mortalities delivering Maximum Yield are likely to be **equally acceptable** from a policy point of view. Total Maximum Yield can theoretically be achieved with some stocks being maintained at a **low biomass level** (“sustainably overfished”, (Hilborn *et al.*, 2015)) or some fisheries having to **close** in order for some others to catch more or be more profitable. Therefore, **Maximum Yield alone might not be sufficient** as the long-term target for fisheries management.

The second main outcome is that **employment** often points towards the opposite direction as the other objectives. In most analyses, it is estimated that **decreasing fishing mortality** towards North Sea-wide MEY also contributes to fulfilling other objectives, such as **better ecosystem status, lower impact on bycatch**, lower fuel consumption and lower carbon footprint (Figure 11). But fishing mortality is linked to a great extent to fishing effort (i.e. number of boats x number of days fishing during the year), and therefore this reduction implies a decrease in fishing activity and employment. According to EU CFP facts⁸ the economic dependency on fishing is very low to moderate for most North Sea regions, **with the exception of Scotland** where it can be very high. Effort reductions have nevertheless been difficult to achieve in the North Sea (Kraak *et al.*, 2013; Scientific Technical and Economic Committee for Fisheries (STECF), 2014), and implementing further reductions towards effort levels compatible with MEY will not be straightforward. MSY appears therefore as an intermediate trade-off between the current situation (“traditional management” in Figure 10) and the more ideal “**zone of new consensus**” closer to MEY.

Figure 11. The relationship between fishing effort and benefits derived from different objectives



Source: (Hilborn, 2007)

⁸ http://ec.europa.eu/fisheries/documentation/publications/pcp_en.pdf

These important considerations may mean that **additional criteria** other than maximum yield **alone** might be considered appropriate by **managers**, for example that **no stock** should be left **below a given biomass level** or, at contrary, considered more important than another. Such an approach would allow satisfying other ecological, economic, social and/or **institutional** while staying in the vicinity of Maximum Yield.

2.4.3. F_{MSY} ranges as a pragmatic policy solution: opportunities and challenges

The idea of **Pretty Good Yield** (Hilborn, 2010) and single-stock F_{MSY} ranges (ICES, 2015f) have been suggested in these **multi-objective** considerations. They estimate the range of fishing mortality which would provide for each stock some long-term yields close to the maximum possible while maintaining **low risk** to the biomass to fall below the acceptable threshold. ICES used an arbitrary **PGY threshold of 95% of maximum yield**, but other values might be decided.

Within these **ranges**, it would be potentially possible to eliminate the combinations of **single-stock fishing mortality** that are mutually exclusive, i.e. which together would lead to undesirable or incompatible outcomes at the regional ecosystem scale (Rindorf et al. 2016), (see also paragraph 5.3). From there, **the remaining F_{MSY} ranges** could provide a flexible **policy framework**, offering a buffer around a target for integrating the annual variations in productivity of the different stocks while defining **clear** limits for the undesirable states that should be avoided.

(ICES, 2015f) though underlined that this flexibility would have a **cost**, and in particular, fishing at levels between F_{MSY} and F_{upper} would increase the dependence of stock and yield on recruiting year classes and increased variability on catch opportunities, with reduced **advice when SSB would fall below MSY $B_{trigger}$** . We argue that the **concept** of the **ranges** is potentially useful and can theoretically address some key operational issues in achieving MSY in a **regional mixed-fisheries approach**, but care must be taken in how it is used.

3. A quantitative bio-economic analysis on the likely consequences of the landing obligation regarding the objectives of the CFP, specially the MSY

KEY FINDINGS

- MSY and the landing obligation are two **independent objectives** of the CFP. The landings obligation **cannot be considered as a direct mean** to achieve MSY.
- When assuming full implementation and no fleet adaptation, the landing obligation would lead to **total landings lower than when discards occur**, because early fishery closures would be triggered by the most limiting stock ("choke species"). This would lead to the under exploitation of the most productive stocks.
- The estimated economic consequences for the North Sea fleets are **very variable across countries and fleets**, with some of them expected to be only lightly affected while some others being more strongly affected. The various **policy adjustments can largely offset** the short-term negative impact.
- There are **many ways** by which fishers can improve their fishing patterns to better adjust to fishing opportunities, but effective **mechanisms incentivising them** to do so are **required**
- **It is not possible to predict how the fishing industry will react** to the landings obligation. Therefore, the current bio-economic analyses can only compare options **on the basis of current fishing patterns**. Practical experience on how fishers adapt to the new management will be gained over the next five years, and models will be updated accordingly.
- The recovery of North Sea cod makes that **most available economic scenarios, parameterised with data up to 2013, are potentially slightly pessimistic**. The improved situation of the stock according to the 2015 assessment indicates that **its "choke" effect has considerably reduced** compared to the situation prevalent during the last decades.

In this chapter, we first deal with a number of **generic considerations** on the relationships between **MSY and the landings obligation**, before moving to the actual bioeconomic considerations. It is underlined that this chapter has **only** focused on those aspects of the landings obligation that are most directly linked to the MSY objectives, and other important aspects linked e.g. to **(i)** the reasons to discard, **(ii)** possible mitigation options and **(iii)** the use of discards in the value chain and have only been briefly addressed here.

3.1. Generic considerations on the relationship between MSY and the landing obligation as management objectives

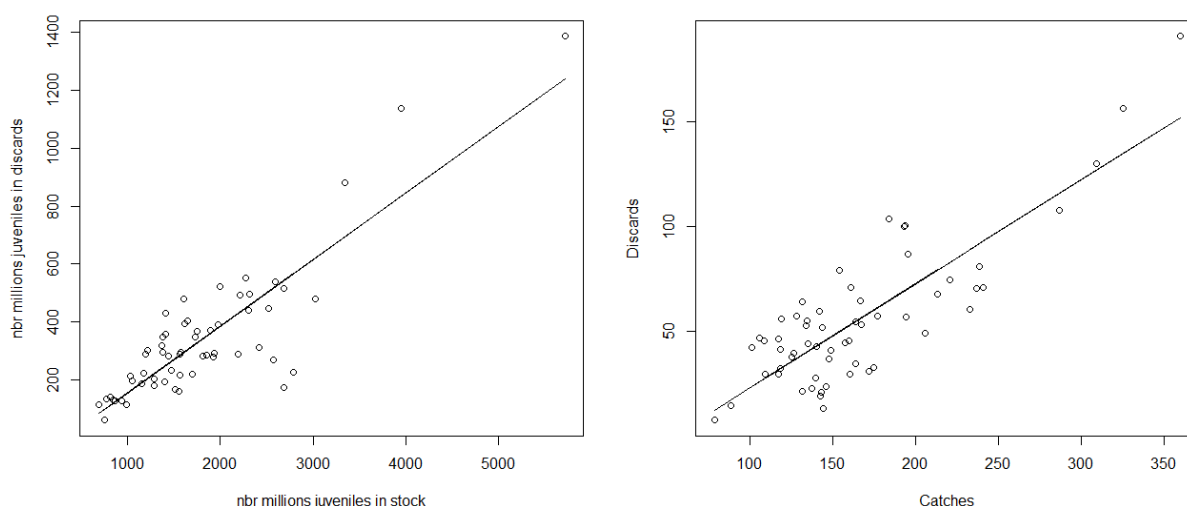
3.1.1. Single-stock approach

The Landing obligation (LO) and the MSY are **two different aspects** of the CFP, and the relationships between the two are **complex**. The Landing Obligation is presented in the EU infographics⁹ as a mean ("HOW") to achieve the **CFP objectives** ("WHAT"): MSY, regionalisation, better science and **multi-annual plans**. But the LO may in reality be considered as an objective on its own, rather than a mean, since the linkages between the LO and the MSY as management objectives are complex and largely indirect.

⁹ http://ec.europa.eu/fisheries/documentation/publications/2015-cfp-management_en.pdf

"Achieving *MSY*" means achieving a level of fishing mortality at F_{MSY} . The fishing mortality accounts for **all catches**, regardless whether these catches are **landed or discarded**. If total catches are correctly monitored and controlled, i.e. that they do not exceed the total advised level, the F_{MSY} objective can be achieved. That means that there is **no direct relationship** between **discarding and achieving F_{MSY}** . In the world, there are examples of fisheries with **limited** discards that are **overfished**, typically **small pelagic** purse seine fisheries such as the Japanese sardine fishery, or many Asian fisheries where all catches are used, e.g. (FAO, 2005). Conversely, there are examples of fisheries with **high discards** that are **not overfished**. In the North Sea, many target stocks are already fished at F_{MSY} , prior to the landings Obligation (Table 2). The most emblematic example of this is the case of **North Sea plaice**, where fishing mortality has been fluctuating around F_{MSY} since 2008, in spite of the high discard ratio around **40%** in weight (ICES, 2015i). Most of the discards for this stock are constituted by **undersized fish with low market value**, and the quantities discarded are fairly well correlated with the year-classes strength (Figure 12 Left). Scientists have thus been able to estimate and predict the quantity discarded accurately enough to account for it in the stock assessment and management advice. Moreover, plaice is not a high-valued species and its **productivity** hasn't reduced in the recent period. Plaice hasn't become a choke species, and discards have fluctuated together with the catches (Figure 12, Right). This implies that to a large extent, **limiting landings through TACs did not induce additional over quota discards**, and total catches have been controllable.

Figure 12. North Sea plaice. Left: Relationship between juveniles number in the stock (at start of one year) and in the discards (within that year), in millions $R^2=0,73$. Right: relationship between discards and catches, in weight. $R^2=0.69$. straight line : linear relationship

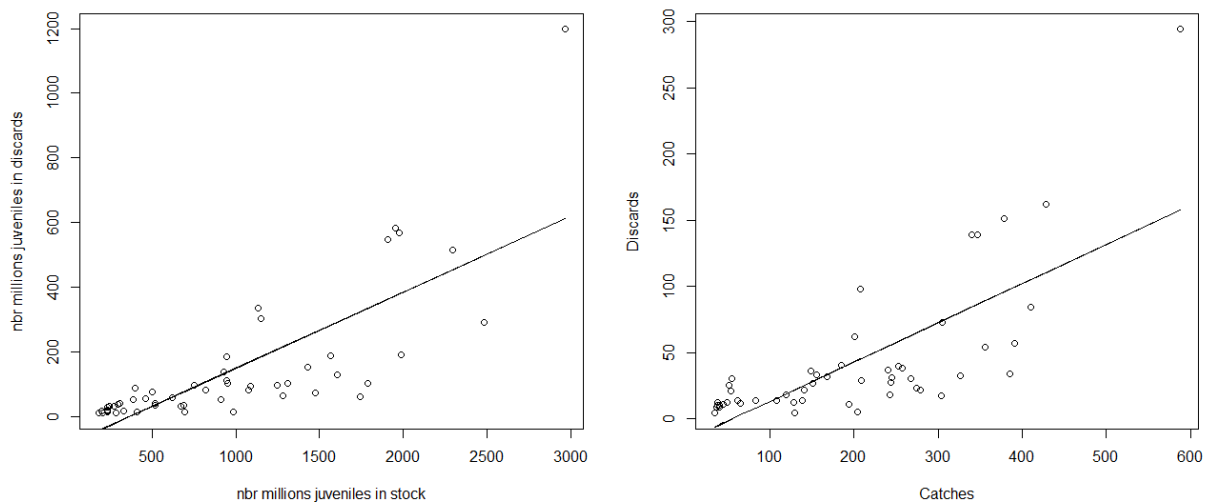


Sou
rce: (ICES, 2015i) data

The situation becomes more **complex** when discards are mainly induced by **the quota management** itself. That is typically the situation of a "**choke-species**", where the management target such as F_{MSY} cannot be easily achieved, because **reductions in TACs do not** necessarily translate into the expected **reductions in fishing mortality**. Rather, they may translate into increased discards if the fishery is mixed and continues fishing for other species beyond the exhaustion of the TAC of the species in question. A major emblematic example of this has been the situation of **North Sea cod** over the last two decades, where the prolonged lack of recovery can largely be explained by the sustained high levels of **fishing mortality** and increased discards and highgrading of cod **above the MLS** (e.g. (Batsleer et al., 2015; ICES, 2015i; Kraak et al., 2013; Ulrich et al., 2011)). For this stock, the relationships

between discards and stock size or catch volume are much more **uncertain** (less linearly correlated on Figure 13), as other factors play a role. In such a case, discards have also been monitored and estimated, and they are also included in the assessment and in the management advice; but the main differences with the case of **North Sea plaice** is that **(1) discards** are much **less predictable** and **(2) total catches** are **less controllable** by management and fishing mortality has remained higher than expected.

Figure 13. North Sea cod. Left: Relationship between juveniles number in the stock (at start of one year) and in the discards (within that year), in millions $R^2=0,58$. Right: relationship between discards and catches, in weight. $R^2=0.54$. straight line : linear relationship



Source: (ICES, 2015i) data

A **third example** to cite could be the case of **Northern hake**, for which **discards have increased** when **fishing mortality has decreased to F_{MSY}** , as the large recovery of the stock has led to its expansion in the North Sea where fishing fleets do not owe enough **historical quotas to cover their increased catches** (Baudron and Fernandes, 2015).

These three examples underline that *discarding and MSY* are not directly linked, and that **different situations** apply to different stocks. Generalising this, (Hall, 1996) distinguished between **Critical Discards** of populations or **species that are in danger of extinction**; **Unsustainable Discards** where, although not currently at risk, continued mortality could put a species or population at risk; **Sustainable Discards** which do not pose a threat to the resource; **Biologically insignificant discards** where the numbers are negligible from the point of view of the population involved; **Unquantifiable Discards** for which a lack of data creates an unknown level of impact. Worldwide, this is likely the category with the greatest number of cases; **Ecosystems impacts** which occur where a complex of species is removed. In many cases the biological consequences of these impacts are unknown; and **Charismatic discards** which involve species of particular significance to groups of people such as marine turtles, dolphins and whales. The capture of these animals may or may not have significant biological consequences.

3.1.2. Mixed-fisheries approach

At a mixed-fisheries regional level, the issue becomes even more difficult to apprehend, because the achievement of the F_{MSY} objective for one less productive stock (or one with little

historical quota) might trigger an **early closure of the fishery** for other stocks (the “choke species” effect). This would lead to catches below the maximum yield for a number of stocks. At this has been explained in ToR 1, the landings obligation might maintain the entire fishery in an **exploitation level below its maximum yield** potential, until the choke stock has recovered and/or the fishery has developed strategies to avoid it. This “choke species” mechanism is the cornerstone of most mixed-fisheries models, and using such an approach it has been estimated that up to 50% of the potential seafood production in the North Sea, Iberian Sea, US west coast and southeastern Australia trawl fisheries would be lost if all species within a mixed species fishery were constrained to levels below F_{MSY} (cf. e.g. (Gourguet *et al.*, 2015; Hilborn *et al.*, 2012; Patrick and Benaka, 2013), though this loss in volume is not necessarily accompanied by a loss in economic yield (Dichmont *et al.*, 2010).

The analyses for the North Sea are provided in more details below in section 3.2.

3.1.3. On the impact of the landings obligation on the estimation of F_{MSY} and F_{MSY} ranges

Incidentally, it must be kept in mind that the landing obligation **might** also affect **the value of the F_{MSY} reference point** itself. As an illustration, we explored the values of F_{MSY} and MSY ranges for the **main North Sea stocks**, using the same data and model as (ICES, 2015g) but varying the **selectivity** parameters across three scenarios: **1)** full **avoidance** of discards, landings selectivity only, **2)** full **catch selectivity** but all discard are landed and contribute to yield (LO full implementation) and **3)** a shift in **selectivity curve** as a proxy for the effect of an increased mesh size.

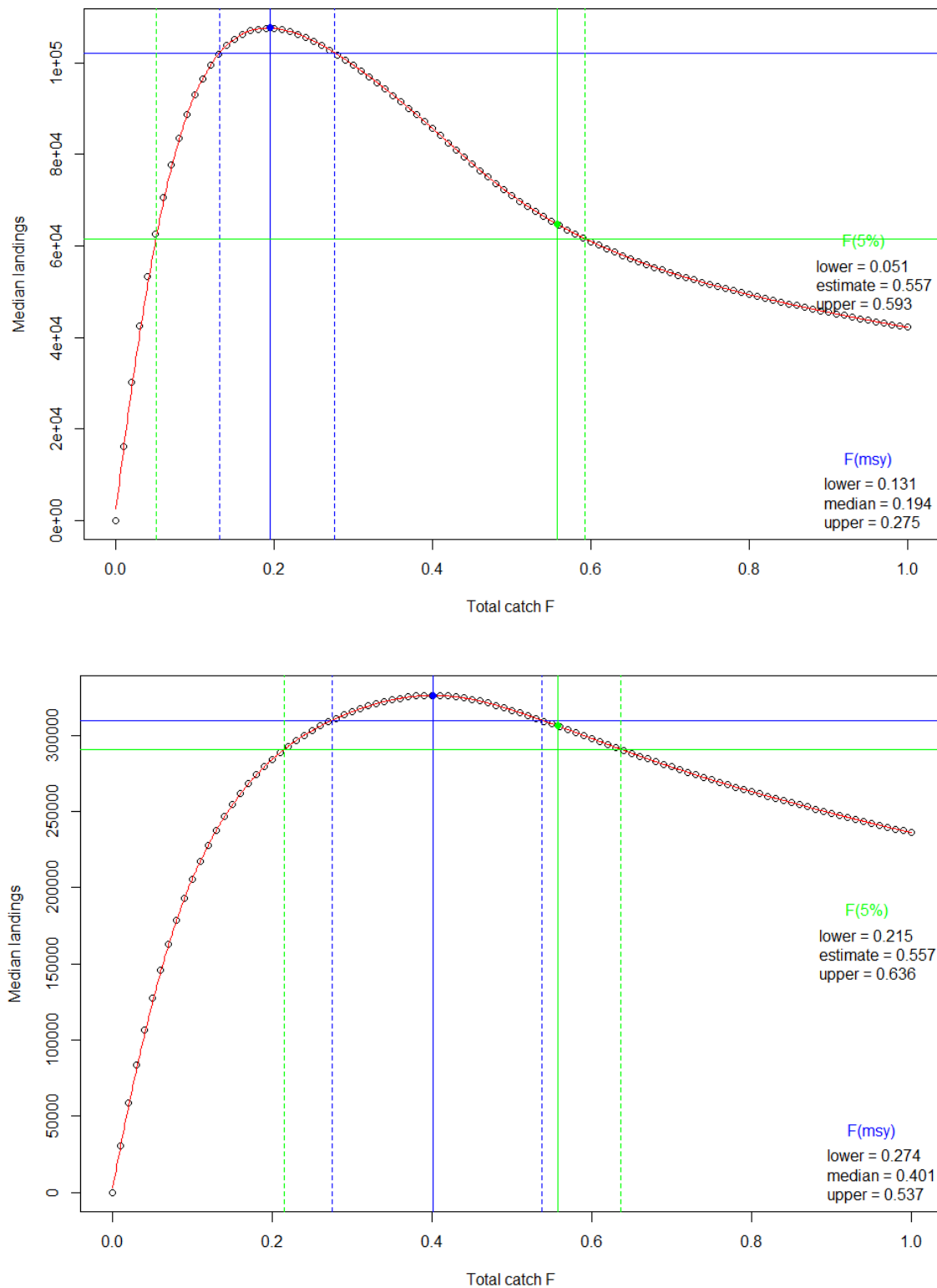
The first two scenarios resulted generally in higher F_{MSY} and a larger F_{MSY} range (

Figure 14, Table 3). Assuming full compliance to the landing obligation and no other change in fisheries pattern shows an **increase in F_{MSY} between 33 % (Cod) and 110 % (Plaice)** and equally higher F_{MSY} ranges. Scenario 3 resulted in similar F_{MSY} values, with no obvious pattern in the direction of change in the F_{MSY} range (Figure 15).

Table 3. Effects of changes in selectivity on F_{MSY} estimates for selected North Sea stocks

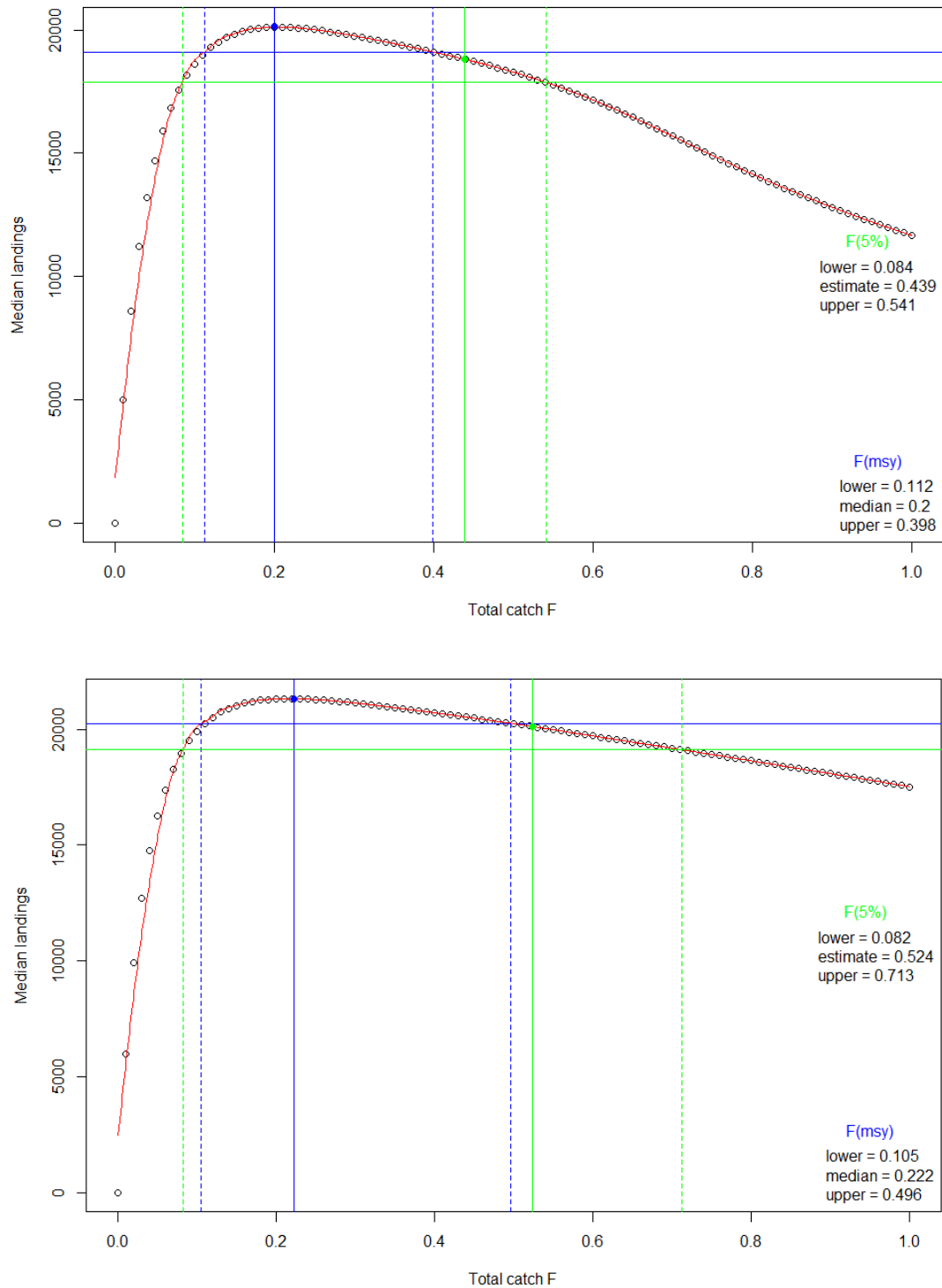
	SPECIES	COD	HADDOCK	SOLE	PLAICE
ICES 2015	MSY F_{lower}	0.22	0.25	0.11	0.13
	F_{MSY}	0.33	0.37	0.2	0.19
	MSY F_{upper}	0.49	0.52	0.37	0.27
Full avoidance	MSY F_{lower}	0.321	0.449	0.151	0.263
	F_{MSY}	0.602	0.657	0.329	0.398
	MSY F_{upper}	0.902	0.928	0.572	0.542
Landing Obligation	MSY F_{lower}	0.266	0.439	0.201	0.274
	F_{MSY}	0.441	0.639	0.393	0.401
	MSY F_{upper}	0.773	0.914	0.591	0.537
Shift selectivity	MSY F_{lower}	0.152	0.209	0.105	0.135
	F_{MSY}	0.235	0.368	0.222	0.2
	MSY F_{upper}	0.375	0.658	0.496	0.297

Figure 14. Effect of the landing obligation on the F_{MSY} value and range on Plaice in the North Sea. Median Yield curve as in Figure 10 and in (ICES, 2015g). Top shows the baseline run similar to ICES 2015 and bottom shows the LO scenario.



Source: DTU Aqua

Figure 15. Effect of shift selectivity (proxy for higher mesh size) on the F_{MSY} value and range on Sole in the North Sea. Median Yield curve as in Figure 10 and in (ICES, 2015g). Top shows the baseline run similar to ICES 2015 and bottom shows the increased selectivity scenario.



Source: DTU Aqua

In summary, this small simulation shows that **when the fishing patterns** change following the LO, the proportion of the **various age- and size classes** of the fish population **change** as well and this affects the perception of the reference points and of the actual maximum yield.

3.2. Modelling the bioeconomic consequences of LO in the North Sea

Many **bio economic models** and studies are available for the North Sea fisheries. They operate at different scales and with different purposes. But they usually build on a similar **mixed-fisheries conception**, where several fleets catch several stocks. When evaluating the impact of the landings obligation, most studies involve the same approach as in (ICES, 2015d) (Figure 4), where the fishery are limited by the TAC of the least productive stock and are forced to **early closure** ("choke species"), **leading to lower effort** and **underutilisation of the more productive resources**. The outcomes are thus fairly similar in trends and magnitude across studies, with some differences linked to the various specifications of the models and of the simulations. We present here some key results available, but other studies not referred to in this report might also exist.

Beyond this choke species effect, there are many **other factors** that can affect the profitability of fishing fleets in the event of a landing obligation (Frost et al., DiscardLess deliverable D2.1; Frangoudes and Guillen, DiscardLess Deliverable D2.2)¹⁰. These factors are of four types:

- Changes in fish price
- Changes in costs
- Changes in catch composition
- Changes in control and monitoring

The models build on an empirical **landing price** for the fraction previously discarded which is usually low, reflecting the **currently limited market opportunities** for undersized fish. But it cannot be excluded that this price can increase when new opportunities develop.

3.2.1. Short-term impact of the landings obligation

The short-term analyses build on static scenarios of what could have happened in a given year, under the landing obligation rules, if current fishing patterns did not change, or if **selectivity** would have been **different** but with the **same stock biomass**. They are thus mainly retrospective analyses rather than predictions, and since changes in fishing behaviour are not included, they can only be considered as potential short-term economic effects.

(Buisman *et al.*, 2013) first made an economic analysis taking the year 2011 as the baseline, and estimated the cost of the landings obligation to be between **6 and 28 millions** euros for the Dutch fleet, depending on (1) the amount of the quota uplifts and (2) the expected mean price for selling undersize fish. Additional costs for monitoring and control should be considered as well.

(Condie *et al.*, 2014a) performed various catch quotas scenarios for the English North Sea Otter trawls, taking the year 2010 as the basis. They argued on the difficulty to derive generic results, as the short-term economic impact would be dependent on the species regulated, the level and composition of catches and discards, the scale of additional quota, and on any change in fishing behaviour. Without any behavioural changes, the average profit **loss was estimated around 14%**.

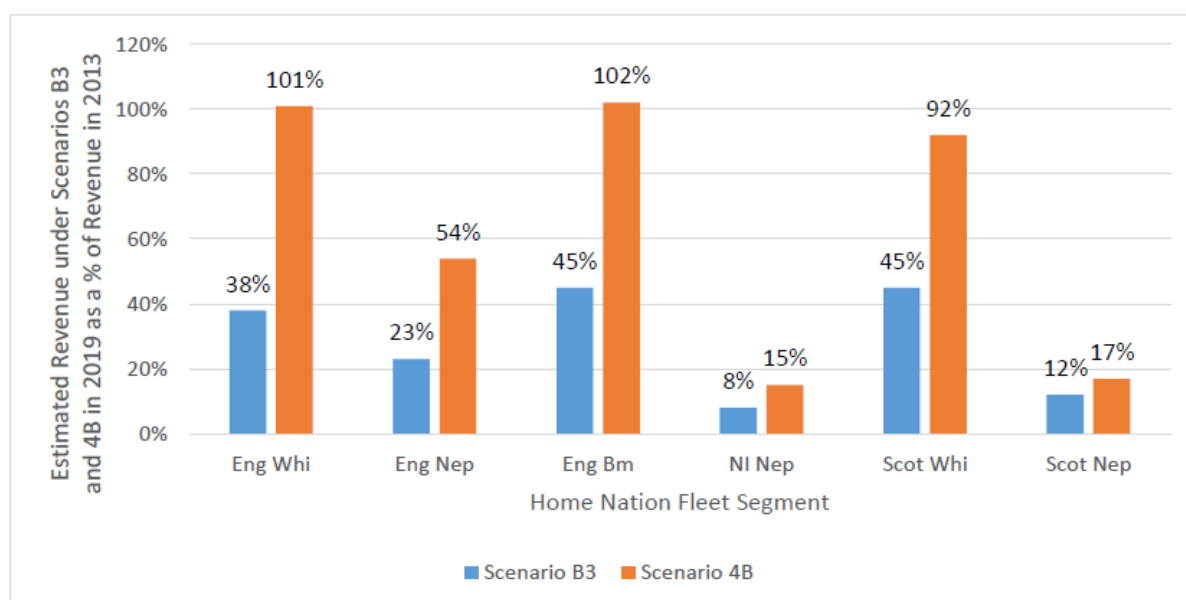
Similarly, The UK organisation Seafish¹¹ has undertaken a comprehensive economic impact assessment that examined a number of **different scenarios** for the **UK fleet**, simulating what could have happened if the landings obligation had been implemented in 2013. **First**, an analysis of the choke species was performed (Russell *et al.*, 2015a). Without changes in fishing

¹⁰ <http://www.discardless.eu/results>

¹¹ www.seafish.org

patterns, the effects were substantial, with species like hake and saithe most likely to trigger early closures due to rapid quota exhaustion. **Second**, these results were translated into the economic analysis of different scenarios of implementation of the Landings Obligation, **with or without policy arrangements** such as quota uplift, catch allowance for zero-TAC stocks, de minimis, interspecies flexibility and survivability (Russell *et al.*, 2015b). The results obtained showed **great differences of impact across fleets and scenarios**, and for many fleets the different policy arrangements would almost compensate for the expected loss of revenue, but not for all.

Figure 16. Estimated revenue of various UK fleets under the full implementation of the landings obligation (as of 2019) as a percentage of the 2013 value under two policy scenarios.



Scenario B3: scenario including quota uplift but no policy adjustments. Scenario 4B: as scenario B3 but including a combination of policy adjustments: 5% de minimis, interspecies flexibility and survivability exemptions.

Source: (Russell *et al.*, 2015b), Figure 10-1 p 118.

A similar analysis was performed for the **Danish fleets**, equally using 2013 as the reference year and testing the impact of various combination of quota uplift, increased costs for sorting and processing the catch onboard, and changes in minimum conservation reference size MCRS (Ravensbeck *et al.*, 2015). For the entire Danish fleets, it was estimated that without quota uplift, revenue would **fall by around 7%** and **gross margin by around 10%**. But if full quota uplift would take place, the effects on the fishery would be fairly reduced (less than 5%), and profitability could even increase if the MCRS would be reduced for some stocks. These results differed across fleets and regions, and the effects would be most severe for the small/medium trawlers in the Kattegat/Skagerrak, but would be quite limited for the North Sea Danish fleet.

These four national studies of the main fleets in the North Sea are fairly consistent in their approaches and their findings. All results clearly show that **without any policy adjustments**, the landing obligation would have a short-term negative impact on the **profitability** of the fleets, by incurring more operating costs not compensated by the low market price for landings **not sold as human consumption**. They also show that one of the most important parameter is the “choke effect”, i.e. how quickly would a fleet reach its catch quota of the least productive stock and what would happen afterwards. In many cases though, it has also be shown that the

various policy adjustments that can be applied would largely **mitigate these adverse effects**.

Importantly, all these studies have been performed with data prior to 2014, and are thus all driven by the major “choke” effect of the North Sea cod, which has suffered from low abundance and low TACs over the last decades. But the latest assessment in 2015 (including 2014 data) has shown **significant improvements in the stock** in spite of continued **reduced recruitment** (ICES, 2015i), and for the first time in the decade of mixed-fisheries advice, cod has been estimated **not to be the most limiting stock** for the North Sea fisheries (ICES, 2015d). In this context, this means that the results presented here are potentially **more pessimistic than the reality**. This has been already demonstrated with the first step of enforcement of the landing obligation in 2016, where the Danish fisheries are expected to get major increase in revenue owing to the major TAC increases, not least for *Nephrops*.¹²

3.2.2. Medium-term effects in relation to MSY

The medium-terms effects of the landings obligation are much more difficult to assess, because the processes that will be going on in the fisheries are still unknown, and largely unpredictable (see chapter 3.3 below). It cannot be ascertained if the fleets will react by some sorts of changes in their behaviour or not, with better or worse compliance, with selectivity improvements or not. There are many factors that can drive the system in one direction or in another, but their effects can lead to dramatic differences in the outcomes, both for the fleets and for the stocks.

This topic is at the heart of the **H2020 DiscardLess** project¹³. At present, results are primarily available comparing some basic scenarios without adaptations, typically contrasting “Business as Usual” with current discards, and “Full implementation” **where all discards are landed and sold**, with full compliance and where the fleets stop fishing when the first quota is reached. This is largely similar to the short-term analyses presented in the previous paragraph. Alternative models are still scarce (paragraph 3.2.2.2 below). When experience is gathered on the actual developments in the fishery, the existing models will be updated accordingly and the bio-economic analyses will be refined. DiscardLess will publish annual policy briefs on this topic between 2016 and 2019.

3.2.2.1. Results with full compliance and no adaptation

Such results have been developed by Hoff and Frost as part of FP7 MYFISH, linked to the DST2 results presented in chapter 2.3.2.2. Again, these runs have been performed with the data up to 2013, where **North Sea cod** was still very much the main choke species in the North Sea.

Four sets of target fishing mortalities corresponding to alternative MSY objectives (**MSY in weight, MSY_w; MSY in value, MSY_v; MEY maximising net present value**), as well as the traditional (current) management plans have been evaluated, allowing or not for over-quota discard of the species included in the model. In the LO case the fishers in reality stops fishing when the most binding quota is exhausted (corresponding to the ‘min’ scenario in (ICES, 2015d)) while they first stop fishing when the least binding quota is reached in the case with no LO (corresponding to the ‘max’ scenario in (ICES, 2015d)). In the **traditional** management case historical catch fractions for all fleets are maintained while they are **allowed to exchange quotas in between country fleets in the MSY/MEY cases**, thus being more able to optimize their outcome and suffer less, especially under the LO. Table 4 displays the

¹² http://naturerhverv.dk/fileadmin/user_upload/NaturErhverv/Nyheder/2015/Forventede_fangstvaerdier_NAER_2016.pdf;

¹³ www.discardless.eu

base indicators resulting from the two scenarios with and without discard allowed, averaged over a 20 years period. The **total catches decrease** in all scenarios when the landings obligation is implemented. The catch is landings plus discards, and thus when all fleets are allowed to discard over_quota catches, the total catches is higher. Table 4 further shows that the landing obligation leads to a **lower profitability** in the **MEY case**, and to a **lower revenue** in the **MSYv case**.

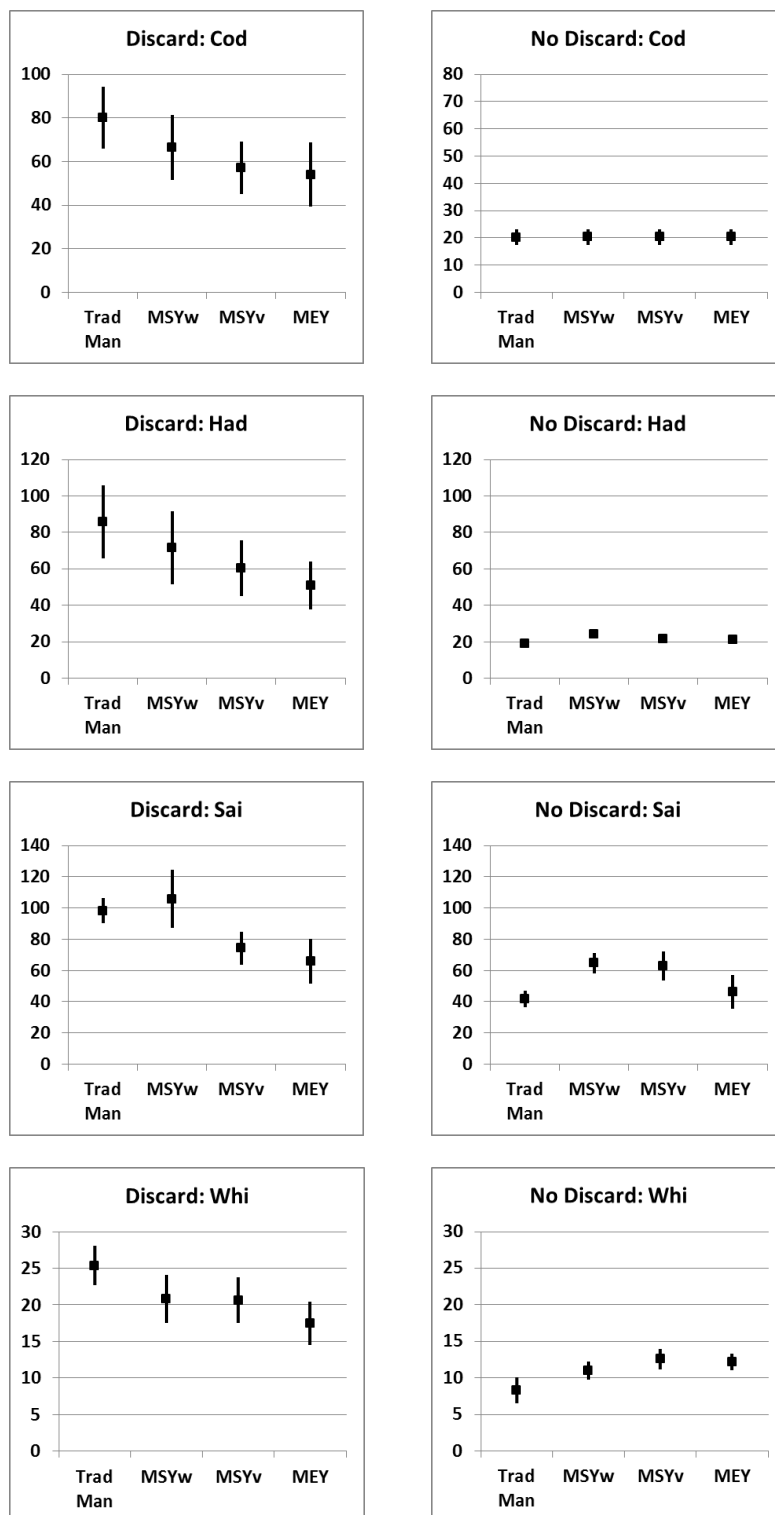
Table 4. Net Present Value (NPV) (mill EUR) catch weight (1000 tonnes) and catch value (mill EUR) for the four scenarios, without and with landing obligation. Total for 24 years (2014-2037)

		Without landing obligation	With landing obligation
Trad Man	NPV	567	546
	Weight	22271	7510
	Value	12252	5557
MSYw: Max Weight	NPV	-2166	458
	Weight	26335	9731
	Value	9857	7518
MSYv: Max Value	NPV	-868	868
	Weight	17609	9675
	Value	10988	8517
MEY: Max NPV	NPV	2086	1550
	Weight	14526	9411
	Value	10058	7721

Source: (Hoff and Frost, MYFISH deliverable D3.2).

In the medium-term (until 2020), a **stringent landings obligation** as simulated here would lead to lower catch and higher biomass for all stocks, similarly to the short-term simulations presented above (Figure 17).

Figure 17. Average yearly (2014-2020) total catch (1000 tonnes), and yearly variation (+/- st.dev) for North Sea cod, haddock, saithe and whiting in the two scenarios with and without discards allowed, for the four options of target fishing mortality.



Source: (Hoff and Frost, MYFISH deliverable D3.2).

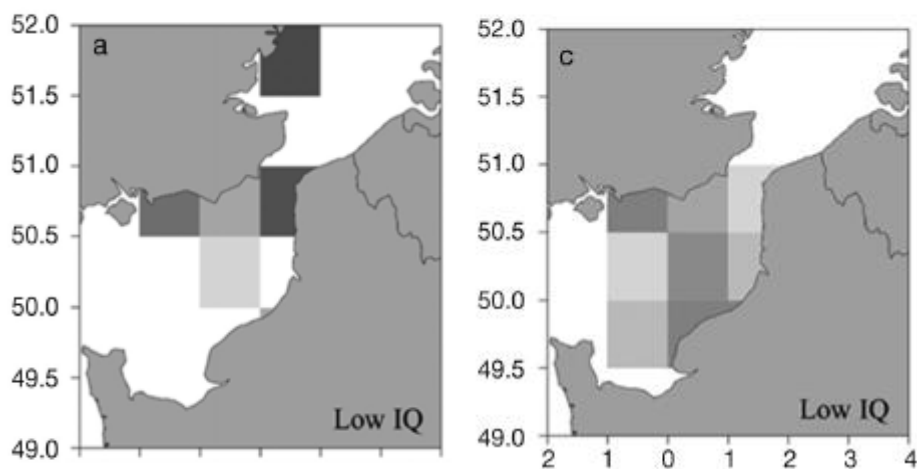
Similarly, Hamon et al. (unpublished, EU Project SOCIOEC) used the results of the static analysis by (Buisman *et al.*, 2013) into a medium term projection, and concluded that profit would decrease by 20% over the next five years in the flatfish fishery.

3.2.2.2. *Modelling fleet adaptation and compliance to the landings obligation*

The results presented above are based on **current fishing patterns**, and would therefore represent the worst case impact assessment. It might be expected that fishers would change their **behaviour to mitigate** this negative impact, for example by avoiding fishing grounds where the **choke species** are most abundant. But this behaviour is not easily captured by scientific models (Fulton *et al.*, 2011b). One way to address this is to model the fishers individually rather than as average fleets.

The **previous bio economic models** presented above dealt with groups, classifying all fishers into “fleet segments” with average fishing patterns. Such models are convenient because they are computationally easy enough to operate, and can therefore cover many fleets and many species. But their main **limitation is that they cannot easily integrate features of human behaviour and fleet adaptation**, since changes in fleet behaviour result in reality from multiple individual decisions made by multiple individual fishers (Andersen *et al.*, 2010; Ulrich *et al.*, 2012). Therefore, such adaptation and choice processes are better dealt with Individual-Based Models (IBM), which allow simulating behaviour at a very small spatial and temporal scale with simplified rules of decision-making, and estimate the average large-scale changes resulting from the sum of these small individual changes. These models are **more computationally complex**, and are thus less commonly used. One such application of an IBM model for assessing the impact of the landing obligation on the behaviour of fishing fleets is found in (Batsleer *et al.*, 2013), for the mixed-fisheries in the Eastern Channel. Assuming that fishers operate under ITQ schemes and can thus plan and adjust their fishery according to their personal fishing opportunities (Poos *et al.*, 2010), the model showed that **a discard ban may force fishers to reallocate effort to areas and periods in which catch of the choke species (here cod) is low** (Figure 18), but that would be at the expense of **lower revenue**.

Figure 18. Modelled spatial allocation of effort in average number of trips per year for French trawlers with a low cod ITQ. Left (a): with discarding. Right (c): no discarding. Colour gradient from 0 (white) to 12 (black) trip per year.



Source: (Batsleer *et al.*, 2013), Figure 5 (Subset)

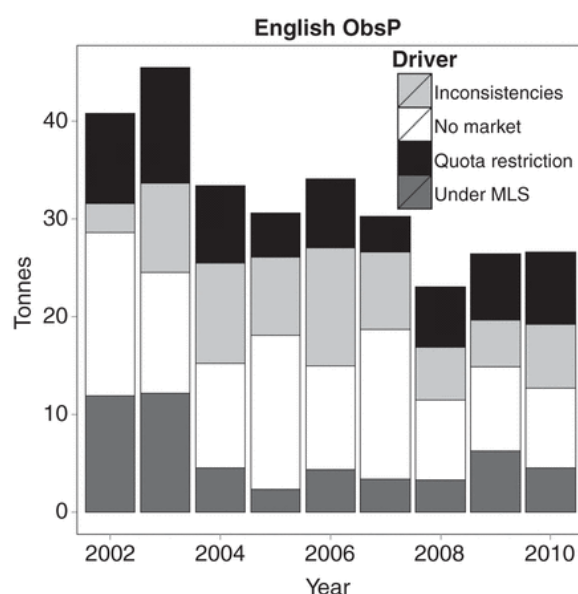
This model, although it remains itself only a simplification of reality, underlines that the incentives to change behaviour as the simple consequence of the landing obligation are complex. (Batsleer *et al.*, 2013) estimated that **in order** to influence this change through **financial penalties to non-compliance**, a fine should be in the order of 20 times the market price of the fish before it can make a significant difference to the fisher.

3.3. Adaptation, changes in selectivity and risks of non-compliance

As it has already been underlined in this report and in numerous other studies, the most uncertain factor regarding the bio economic impact of the landing obligation on the fisheries, and on the achievement of the MSY objectives, is **thus the human factor**, with the decision to adapt or not and comply or not to the obligation to land catches and, as (or more) importantly, to report all catches.

Discarding is motivated by **many technical, economic, regulatory and socio-cultural** factors which are often interlinked (Catchpole *et al.*, 2005; Rochet *et al.*, 2014), and **these drivers will not disappear** only because **discarding becomes forbidden**. As an illustration, the figure below quantifies the main drivers of discards for English fleet (Figure 19), emphasising that discards are highly variable and that the relative importance of the various drivers may also vary. Different causes of discarding will also create different incentives to change behaviour or not.

Figure 19. The estimated weight of discarded fish, commercial cephalopods, and crustaceans generated by the English fishing fleet (2002–2010).



Source: (Catchpole *et al.*, 2014)

3.3.1. Selectivity improvements and discard mitigation

There is a vast amount of literature on discards mitigation, which is only briefly discussed here. There are many ways in which avoidance could be achieved.

One obvious solution is the **increased use of selective gears**. There is a long history of development in this domain, and many technological solutions are already available, but the uptake has remained generally low. Some work is being done to collate and synthesize the outcomes of numerous selectivity trials in an accessible format (Frandsen *et al.*, 2015; SEAFISH, 2015), see also <http://www.seafish.org/geardb/>. Pilots are also conducted in several

fisheries to trigger industry-led development of selective fishing gears adapted to fishers' individual needs (Mortensen *et al.*, 2015). Also, it may be possible to enhance avoidance of unwanted catches through effort displacement, either voluntarily or through e.g. Real Time Closures (Kraak *et al.*, 2015; Little *et al.*, 2015). Another option would include **more efficient quota trading** (Hoefnagel *et al.*, 2015), although there are indications that member states will rather be less encline to swap quotas to limit risk of quota limitations for their own fishers.

(Sigurðardóttir *et al.*, 2015) performed a comparative SWOT analysis of twelve options, including **technical, management and market mitigation measures**. They concluded that such measures would be more successful in achieving their goal when used in **combination**, rather than in isolation. Nevertheless, it was also demonstrated that most measures may have (unwanted) spin offs and ask for adaptive management approaches. Co-management was repetitively scored as a strength, making it a core ingredient for a successful approach to develop and implement reduction strategies.

Without going into **further details**, it is then clear that many options to mitigate discards already **exist**, and new options are developing as discarding become illegal. But this development is largely unpredictable, and must be closely followed, as negative incentives and non-compliance may also occur instead. The key barrier is how to trigger the proper incentives that would increase the uptake of selectivity measures by the industry.

3.3.2. Risks of non-compliance

Experience from countries where a discard ban has been implemented (Alaska, British Columbia, New Zealand, the Faroe Islands, Norway and Iceland) highlights that this can result in a reduction of discards, but relying upon a high level of surveillance and/or economic incentives to encourage fishers to land more of their catch (Condie *et al.*, 2014b). All the bioeconomic analyses presented above show that at worst, **the LO can have significant negative economic impact to the fisheries**, potentially triggering a reaction through fishers adaptation. But it cannot be ascertained whether this reaction will actually take place, for three reasons.

First, the various **policy adjustments** and exemptions that will be implemented make it difficult to evaluate whether this impact will be simply mitigated, nullified or even possibly turned positive. This would help the industry in the short-term, but may also reduce the economic incentives to change fishing patterns in the medium-term. **Second**, the landing obligation suffers from a **legitimacy crisis**, with the fishing industry feeling that the decision on LO was made by people that lack understanding of their daily practices (Borges, 2015; de Vos *et al.*, 2016), and only a diligent dialogue and sustained collaboration at national level can revert this crisis. **Third**, the proper mechanisms of adaptation need to be incentivised.

There are though many known factors that can insure the success or the failure of **discard reduction programmes**. (Catchpole and Gray, 2010) argued that the following conditions must be met for enhancing the chances of success:

- perceived crises from the stakeholders side
- economic incentives
- stakeholder participation
- adequate funding
- expert knowledge
- strong leadership
- strict enforcement

Ultimately, if the industry does not comply with the landing obligation and does not fully report catches, **reduction of discard-based fishing mortality will not occur**. Rather, there is a certain **risk** that fishing mortality increase instead, if the TACs are increased as catch quota,

but unreported discarding continues. This can be potentially worsened by the mechanisms of **inter-species flexibility** (STECF 2013; Woods et al. 2015). Therefore, great care must be given over the next few years, in order to closely follow whether and how fishers will react during the transition period from now to 2019.

3.4. **Summary: A quantitative bio-economic analysis on the likely consequences of the landing obligation regarding the objectives of the CFP, specially the MSY**

At this stage, it appears quite difficult to **assess the true effect of the landing obligation on the objectives of the MSY**, and to predict the evolution of the situation from now to 2020, because the potential paths of development are numerous. And which path will be followed in each fishery is to a large extent conditional on social and cultural factors.

This chapter has highlighted that the MSY and the landing obligation are two different objectives, with unclear relationships between the two. Many processes are engaged, which potentially conflict with each other:

- **In a single-stock context**, a fully enforced landing obligation would imply a better monitoring and controllability of the total catches of the stock. Better data would mean a higher quality of the scientific knowledge, and better controllability would mean that the advised catch levels, decided in accordance with the MSY objective, would be respected and fishing mortality would be maintained at F_{MSY} . This positive process has arguably been the main thinking motivating the landing obligation.
- **In a mixed-fishery context**, a fully enforced landing obligation might trigger early closures of the fisheries, when a TAC is reached first ("choke effect"). This would potentially force the fishery at levels below those giving MSY for other stocks, until the choke effect has been mitigated.
- **This choke mechanism** is then expected to trigger bottom-up mechanisms of adaptation of the fishing industry, which may develop paths towards more selective and adaptive fishing in order to make best use of the fishing opportunities. In theory, this would lead to the optimum combination of exploiting the most productive stocks and avoiding the least productive ones, which would achieve the MSY objective in the mixed-fishery context. Many options to achieve this already exist, and others are to be developed on the way in a collaborative process led by the fishing industry.
- However, this mechanism may also lead to **significant** negative economic impact in the **short term**. Therefore, a more pessimistic scenario is also likely, as this situation might trigger **mechanisms of non-compliance and resistance**, rather than **adaptation**. Past experience with the North Sea cod management plan have already shown how politically difficult it is to enforce the reductions in effort that would be necessary to achieve recovery of the weakest **stock in a mixed-fisheries**. In case of non-compliance, the MSY objective will not be achieved for the weakest stocks as uncontrollable **over quota discard would continue**.
- **Policy adjustments are being implemented** to mitigate these short-term negative impacts, such as **TAC uplifts, exemptions and inter-species flexibility**. These have been estimated to reduce, or even **nullify the negative impact**, but they might then also **nullify the incentives** to develop **selective fishing**. Furthermore, these adjustments might help for a better reporting of catches to some extent (what was previously discarded can be reported as landings as long as the TAC adjustment is higher than the potential discard); but they might not constrain fishing mortality, as

unreported overquota discarding might still take place when the adjusted TAC becomes constraining. In that case, fishing mortality could even increase unnoticeably.

- Additionally, it cannot be excluded that **new market opportunities will develop** for the fraction of catch previously discarded, ensuring a higher landing price than the current levels. This would reduce the negative economic impact of the LO, but the fisheries would then develop towards a system of better discard use rather than better discard avoidance. These aspects are not developed further here, but should be considered closely.

This summary highlights the **difficulty** to align the intention of the landing obligation, with its implementation in practice in **highly mixed-fisheries**. There are conflicting mechanisms in the system that can potentially drive the fishery away from its path towards MSY, and achieving both the **MSY and the LO objectives at the same time**, and within a short time frame is an ambitious task. The incentives to comply are rather weak, and the LO suffers from a lack of legitimacy in the views of many stakeholders.

It is nevertheless possible to **achieve all objectives by 2020** as stated in the 2013 CFP, but that requires that all necessary elements are in place to prevent the vicious circles to dominate, including:

- Appropriate levels of **quota uplifts** to account for the expected additional landings that were discarded before;
- A high level of surveillance and monitoring to ensure that the fraction previously discarded is reported and accounted in the TAC;
- A **sustained dialogue** at national level to insure better acceptance and legitimacy;
- Develop bottom-up mechanisms that can stimulate the development and the uptake of **selective fishing practices**;
- Alternatively, if selectivity cannot be achieved, **facilitate the inclusion of discards in the value chain**, which could add some value to this fraction of the catch. Some value-chain models like in Iceland or in Norway might be envisaged.
- Additionally, a flexible management **approach based on MSY ranges** may limit the most adverse choke species effects and allow adapting to the changing productivity of the various stocks (see section 5.3).

4. An assessment of the main ecosystem impacts of the landing obligation in the North Sea

KEY FINDINGS

- The actual role of discards in the ecosystem is **still little known** but **foodweb effects beyond scavengers** may be limited
- **Seabirds and benthic scavengers** are the main populations feeding on discards.
- Some local impact might occur but **the landing obligation might not threaten scavengers at population level**
- The main threat identified is from **increased competition** by scavenging seabirds on other seabird species.
- **A gradual reduction may potentially impact the ecosystem less** than an abrupt elimination of discards
- It is **debated whether improved selectivity is ecologically beneficial** or not in the long-term
- The most important ecological benefits are obtained by **avoiding catching discard** in the first place, **primarily by limiting fishing mortality**
- It is expected that improved knowledge will continue to develop in the coming years

Assessing the actual ecosystem effects of discarding is a difficult issue, with many unknowns remaining. It hasn't been much studied before the recent policy focus on the landing obligation. Direct observations are technologically difficult to gather and are scarce. Some literature review was conducted by (ICES, 2015j) and as part of the DiscardLess project (Feekings et al., 2015, Deliverable D1.1), that is used here. This scientific field of science is though receiving increased focus now. New knowledge is being gathered, that may lead to a better understanding of the **ecological role of discarding and of selective fishing in the near future**.

4.1. Contribution of discarded fish to commercial fish stocks

If the mortality of discarded individuals is low the issue of discarding becomes less of a concern (Mesnil, 1996). However, in many circumstances this is not the case and the mortality of discarded individuals can represent a **significant** portion of **total fishing mortality**. Many factors influence the survival of discarded fish, including technical factors (gear type, catch volume and composition, towing speed, haul time and duration, time on deck, handling procedures), environmental conditions (water and air temperatures, light conditions, anoxia, sea conditions, depth of capture), and biological attributes (**fish size and species, behaviour, and physiology**) (STECF 2013). Discarded fish of most demersal species do not survive well – potential exceptions include flatfish such as plaice, and certain elasmobranchs (skates and rays) may also be resilient. In theory, discarded *Nephrops* should survive well, although the survival rate is very dependent on handling processes and the season of the year. As for other sedentary species, the distance from fishing ground can also have an **effect on survival**, if they are thrown overboard while the vessel steam away and they fall on a potentially unsuitable habitat (Evans et al., 1994). An additional source of mortality for crustaceans is associated with their shell durability, and subsequently the stage of moult (Broadhurst et al., 2006).

In the stock assessments performed by ICES, only *Nephrops* include some parameters of discard survival as part of the management advice (25% survival rate on average in the North Sea). **For the other stocks**, it is assumed that **all discard die**, and therefore in terms of stock assessment, it does not make **any significant difference** if the discards are thrown back to the sea or brought to land as long as no unreported/unobserved discards occur under the landing obligation. If discards quantities are reduced, this will translate into a lower mortality of younger ages. In the medium-term, this should enhance the spawning stock biomass, but it cannot be ascertained whether this will also enhance future recruitment and productivity.

A specific issue with regards to commercial species relates to the potential benefits of *Nephrops* as **scavenging on fish discards**. Direct observations of this are though scarce across the various in situ analyses. (Bergmann *et al.*, 2002) reported observations of *Nephrops* being an important megafauna scavenger in the Clyde Sea. Some observations were also made by Feekings in the Kattegat (unpublished data). Ultimately, the actual dependency of *Nephrops* populations on fish discard remains largely unknown but may potentially play a role.

4.2. Qualitative considerations on the ecosystem impacts of the landings obligation in the North Sea

4.2.1. Effects on seabirds

Some studies have estimated that **seabirds** consume up to **60% of discarded animals** (Catchpole *et al.*, 2006; Furness *et al.*, 2007), but other studies have shown that most discard sink fairly rapidly and are only shortly available to seabirds. In any case, seabirds represent clearly a **major group feeding** on discards (Wassenberg and Hill, 1990). The effect of a reduction in food for seabirds might lead to **decreased** populations of the species most dependent on discards such as large **generalist seabird species** (Bicknell *et al.*, 2013). These species (such as the great skua) have adapted to the discards food availability, and dominate many seabird communities. It is however expected that those will be able to buffer a decline in discards by switching **to feed on alternative food**. While it can thus be argued that a reduction of discards would then bring seabird populations to a more natural equilibrium, it is nevertheless noted that the impact would potentially rather be on other species than these generalist species, as those may increase competition and domination on other species of birds, either by direct predation or by stealing from their other sources of food (Votier *et al.*, 2004).

4.2.2. Effects on benthic and demersal scavengers

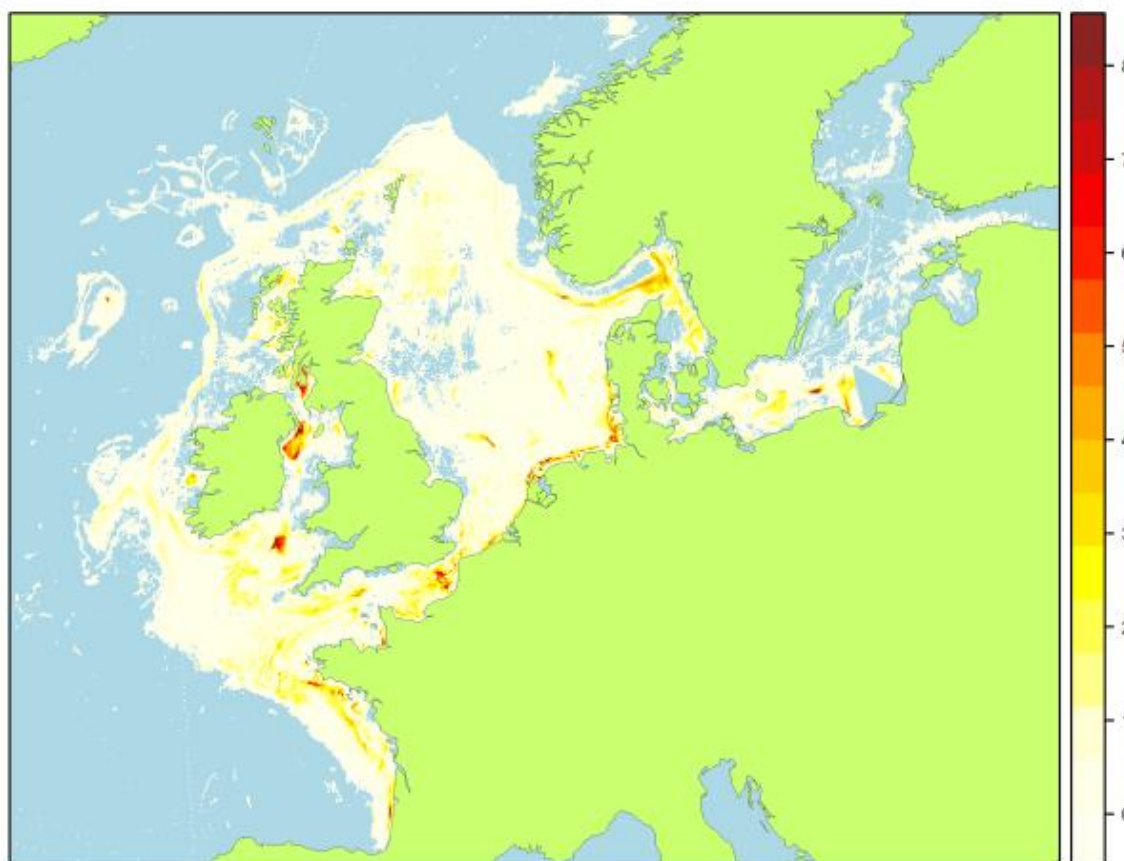
The new policy may also have an impact on **benthic and demersal species** who consume discards **on or near the seabed** (Depestele, 2015). The effect of this shortage depends on the ability of the scavengers to compensate by switching to **other food sources**, since it has been shown that the consumption of discards is dependent on the **type of fish** discarded (Sotillo *et al.*, 2014), and on the changes in conversion efficiency of their food. This may limit the direct effects on these species, but may also cause unpredictable cascading effects on other species through increased predation and/or competition. A wide range of other species has been identified to scavenge on discards, from marine mammals to benthos (Svane *et al.*, 2008; Wassenberg and Hill, 1990). Scavengers range from those that are close to obligate scavengers through to predators that will occasionally scavenge.

(ICES, 2015j) identified key scavengers from field studies which investigated the aggregation of organisms after presenting discards to them as bait. In European waters, most studies were conducted in the North Sea, the Irish Sea or the Clyde Sea. The main scavenging species (in

terms of biomass observed in trials) are common whelk (*Buccinum undatum*), Hermit crab (*Pagurus bernhardus*), common sea star (*Asterias rubens*), Edible crab (*Cancer pagurus*), swimming crabs (*Liocarcinus sp.*), and common littoral crab (*Carcinus maenas*). *Nephrops* has also been observed, but less frequently. Among fish species, the most obvious candidate would be the hagfish (*Myxine glutinosa*) (Martinez *et al.*, 2011), but other common species were flatfish (mainly dabs *Limanda limanda*), whiting (*Merlangius merlangus*) and haddock (*Melanogrammus aeglefinus*) emphasizing the continuum between predator and scavenger.

It is difficult to quantify the importance **of discards** compared to the **abundance** of other **dead biomass in the sea**. **Seasonal and diurnal feeding patterns** may affect food partitioning, and there is likely a high variability in the spatio-temporal effects of discards scavenging (Depestele, 2015). The spatial overlap between discards and benthic scavengers is an important factor. Fishing effort is not uniformly distributed in the North Sea (Figure 20)(ICES, 2014). The gears leading to most discards are mainly concentrated in some given areas, the shallow waters in the Southern North Sea for beam trawls, and around the *Nephrops* fishing grounds for trawlers.

Figure 20. Fishing intensity (surface + subsurface) for otter trawls, beam trawls and dredges, combined for the years 2009-2012. The colour in each 0.05 × 0.05 degree grid cell corresponds to the swept area ratio (average number of times fished per year).



Source : (ICES, 2014) Figure 1.6.6.5.5

Discards are likely concentrated in these areas of more intense trawling, so the potential impact of the landings obligation might be **local rather than regional**.

There is little information available on the spatial distribution of benthic scavengers in comparison. (Callaway *et al.*, 2007) have demonstrated that the current populations of benthic

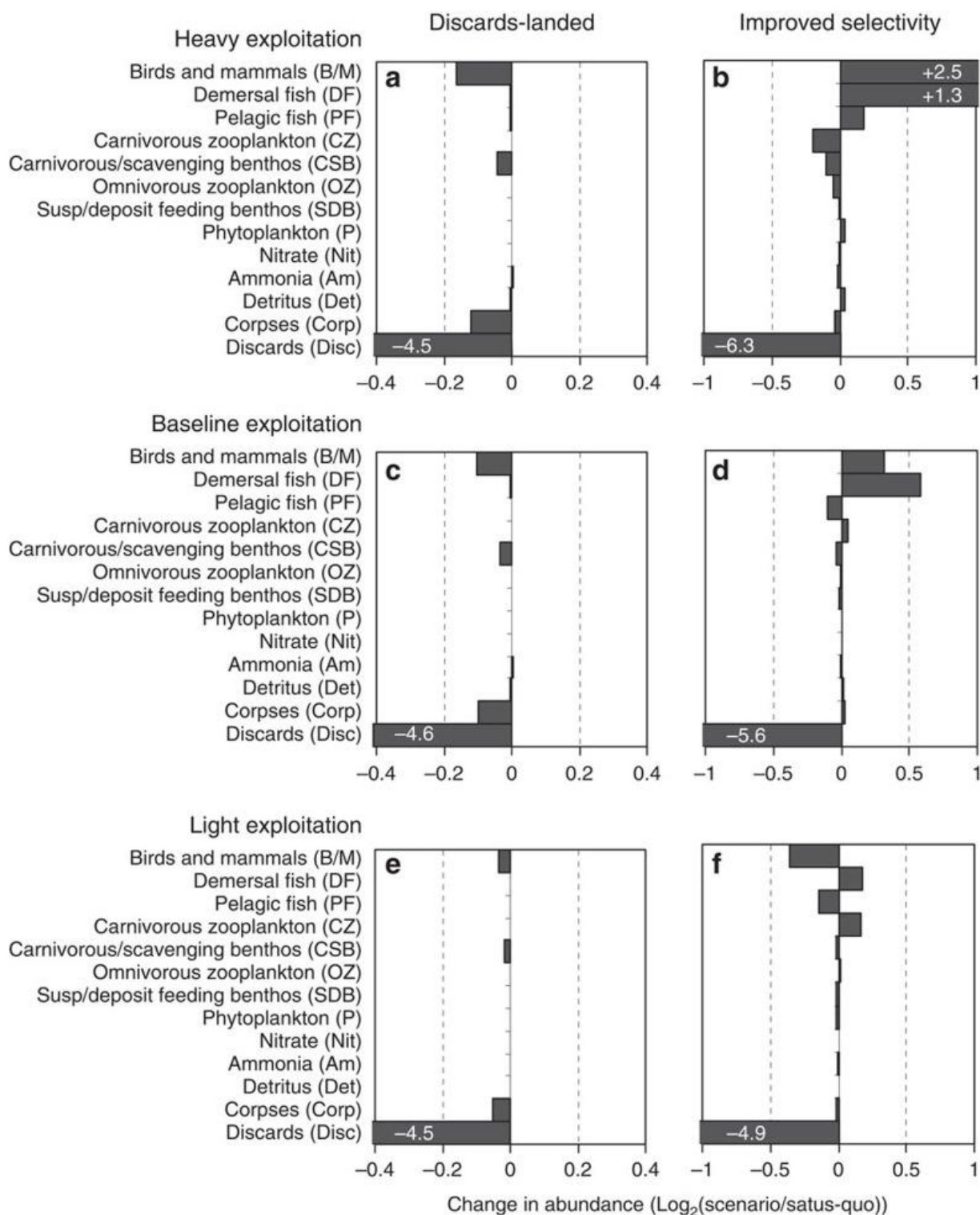
scavengers are those who have resisted to a century of trawling, and the main species are largely distributed all over the North Sea. Without certainty, one may thus assume that although local effects might occur, a reduction of discards may not threaten the benthic scavenging species at the population level.

Another important point to consider is also **the rate** at which changes occur. (Fondo *et al.*, 2015) have shown for another ecosystem that **a gradual reduction of discards** is beneficial because it would increase the resilience of scavenger species through adaptation to food shortage, but that conversely, an abrupt reduction may be detrimental as it may affect ecosystem stability.

4.3. Quantitative impacts of the landings obligation in the North Sea

Heath et al (2014) have modelled the ecological effects of a discard ban, and in particular the indirect effects on other components of the ecosystem through **trophic cascades** (Figure 21). The study suggested that if **discards** were landed, there would be small negative effects on birds, mammals and scavengers (left column). However, if the discards were avoided (i.e. not caught at all through improved selectivity) there would be **significant benefits to birds, mammals and the demersal fish biomass**. But some limited negative effects were observed for the **pelagic fish** through trophic cascades on the pelagic fish biomass. This is reinforced if fishing mortality decreases at the same time, since the increased biomass of **demersal stocks would increase predation on the pelagic communities**.

Figure 21. Sensitivity of food web components to landing obligation scenarios. Horizontal bars indicate the relative abundance of food web components under landing obligation scenarios relative to 'status-quo' discarding, for three levels of fishing intensity. Left column (a,c,e): sensitivity to 'discards-landed' scenario, right column (b,d,f): sensitivity to 'improved selectivity'.



Source: (Heath *et al.*, 2014)

4.4. Improved selectivity vs. balance harvesting

More generically, the landing obligation has raised a **fundamental** issue, which is whether improved **selectivity** is actually **ecologically beneficial** or not. This question is not fully resolved scientifically. In the recent years, many voices have been raised to **challenge the established selectivity paradigm** that fishing on juveniles is damaging and wasteful, arguing that a '**balanced harvesting**' (BH) across all species and size classes would provide high yield and improved **ecosystem resilience and stability** (Garcia *et al.*, 2012; Kolding *et al.*, 2015; Zhou, 2008), and less fisheries-induced evolution (Marty *et al.*, 2014). Since then, analyses have been refined to assess the actual benefits and limits of the BH idea in the real world (Garcia *et al.*, 2015), leading to a more nuanced view, with many uncertainties remaining due to the complex interactions of species and fisheries in open marine fisheries. In particular, BH does not appear to be **technologically feasible**, economically viable, and **politically manageable in mixed demersal fisheries as those in the North Sea** (Burgess *et al.*, 2015; Reid *et al.*, 2016).

Nevertheless, even if a fully balanced fishing will not occur, it must be kept in mind that the quest for fully selective fisheries avoiding juveniles may have unintended ecological effects in the medium and long-term, and **there is maybe an optimum selectivity** in between these two extremes (Froese *et al.*, 2016). Ultimately, **the clearest ecological benefits remain in limiting fishing mortality overall.**

4.5. Summary on ecosystem effects of the landing obligation

The ecosystem effects of discarding, and of its reduction with the landing obligation, are still largely unclear. The quantification of the role of discards in the marine foodweb is difficult.

In the short-term, it can be expected that some changes will mainly occur in the seabirds and benthic scavenging communities. From the limited knowledge that is gathered here, it may though not lead to dramatic collapse of populations, since most scavenging species are able to feed on a wide variety of food sources. They also occur in large population numbers, so it can be expected that these have the required buffer to adapt.

The main threat identified is on some seabird species that may be significantly affected by increased predation and/or competition by scavenging birds. In this regard, it is argued that the **ecosystem** would better **adapt** to potential food shortage if the **landing obligation** was implemented **gradually rather than abruptly.**

An important discussion that is taking place is whether it is **ecologically** meaningful to bring **biomass to land rather than discarding** it. The study by Heath *et al.* (2014) shows that this effect is quite limited (left column on the Figure 21) beyond the actual scavenger groups. There is little evidence that landing the **discarded biomass** affects other species further in the **food web**. The importance of this question is thus rather an **economic question** (because of the extra costs linked to sorting, handling on board, shorter fishing trips and processing onshore) more than an ecological one.

Clearly, the **main ecological benefits are found in the reduction of catching discards in the first place, primarily through reduction in fishing mortality.**

5. Recommendations on the best way to implement the discards plans and multiannual plans according to the different scenarios at regional level

KEY FINDINGS

- MSY is the most important goal
- Acknowledge the fuzzy and variable nature of MSY
- Make smart and transparent use of MSY ranges
- Maintain institutional sustainability and reactivity
- Support the legitimacy of the landing obligation
- Be precautionary over the next five years

This ToR is difficult to address, as it is not exactly the **role of science** to make generic **policy recommendations**. Usually, scientists provide factual considerations on specific requests, often channelled through ICES or STECF, but usually not as individual and personal views.

The topics below are therefore merely **a reflection** from the author on a **small number** of selected **issues** that have been witnessed to be of importance in the current political debate. These are built on own experience as well as on the knowledge gained through writing the present report, and can hopefully contribute to achieving the **CFP objectives** in spite of the major sources of complexity, variability and uncertainty surrounding them.

5.1. MSY is the most important goal

The 2013 CFP is a major document containing many words, covering different aspects, and many objectives. These objectives cannot always **easily translate into operational and quantitative targets**. There is also confusion whereas the landing obligation is an objective in itself, or a mean supposed to support the achievement of the other objectives. The multiplicity of goals may dilute the political efforts into many directions, and we witness that the landing obligation has overshadowed some of the previous developments in **ecosystem-based marine management**. Considering the **unclear** linkages between **MSY and the landing obligation**, we consider that achieving exploitation rates able to produce maximum sustainable yield is likely the **most important objective** and should be prioritised. Even **in a single-stock perspective**, MSY as a management objective brings a lot of **ecological benefits compared to the previous management frameworks** based on the precautionary approach, thus contributing directly and automatically to ecosystem-based management (Mace 2001; Patrick & Link 2015; Hilborn 2007; Hilborn 2011; Rindorf et al. in press) as well as to high yield and economic returns. Progresses towards this objective were already observed before the implementation of the 2013 CFP, and these should not be jeopardised.

5.2. Acknowledge the fuzzy and variable nature of MSY

As at been explained at length in this report, a major impediment to this first recommendation is the difficulty to **define and quantify this MSY objective**. For scientists, MSY is a Holy Grail. Its quest is a noble cause, but it may never be found, and one may never know how it looks like and whether it has been truly reached. By nature, F_{MSY} will always be **varying** even in a **single-stock context**. And it is **less definable** in a **regional ecosystem context**. Without any doubt, the multiple biological and technical interactions that are well known and well quantified in the North Sea cannot be ignored. Defining what is to be maximised (what is MSY) and whether **it is a limit or a target** is therefore not a **scientific question** alone. The fact that scientists argue against each other on the value and the appropriateness of MSY reflects this fuzzy border between science and policy (Mesnil, 2012). Therefore, MSY-based management requires **first** that **this uncertain state of nature is understood and accepted**. Only after can the necessary trade-offs be acknowledged, and the political choices be made.

We argue thus that the MSY concept needs **adaptation**, not wholesale replacement (Kempf et al., in press; Rindorf et al., in press). Considering MSY as a **multidimensional area** rather than a point estimate is a new and pragmatic management approach to this central issue of definition and quantification of the MSY objective. This approach creates a formal frame which **prioritises the avoidance of risks** ("staying away from where we do not want to be") **to the achievement of a given optimum** ("being where it is exactly best"), thus circumventing some of the most irresolvable definition questions while maintaining a productive ecosystem and viable fisheries (Degnbol, 2015).

5.3. Smart and transparent use of MSY ranges

Following these arguments, it has been proposed to **define ranges of/around F_{MSY}** for each of the main stocks, as a primary management tool (Hilborn, 2010) Kempf et al., submitted). This "**Pretty Good Yield**" approach is conceptually appealing to address the issues above, but it also requires the **quantification of these ranges**, and in particular of the upper value above F_{MSY} point estimate. This one relies on an important **subjective choice**, which is the acceptable threshold of loss of yield compared to the maximum estimated.

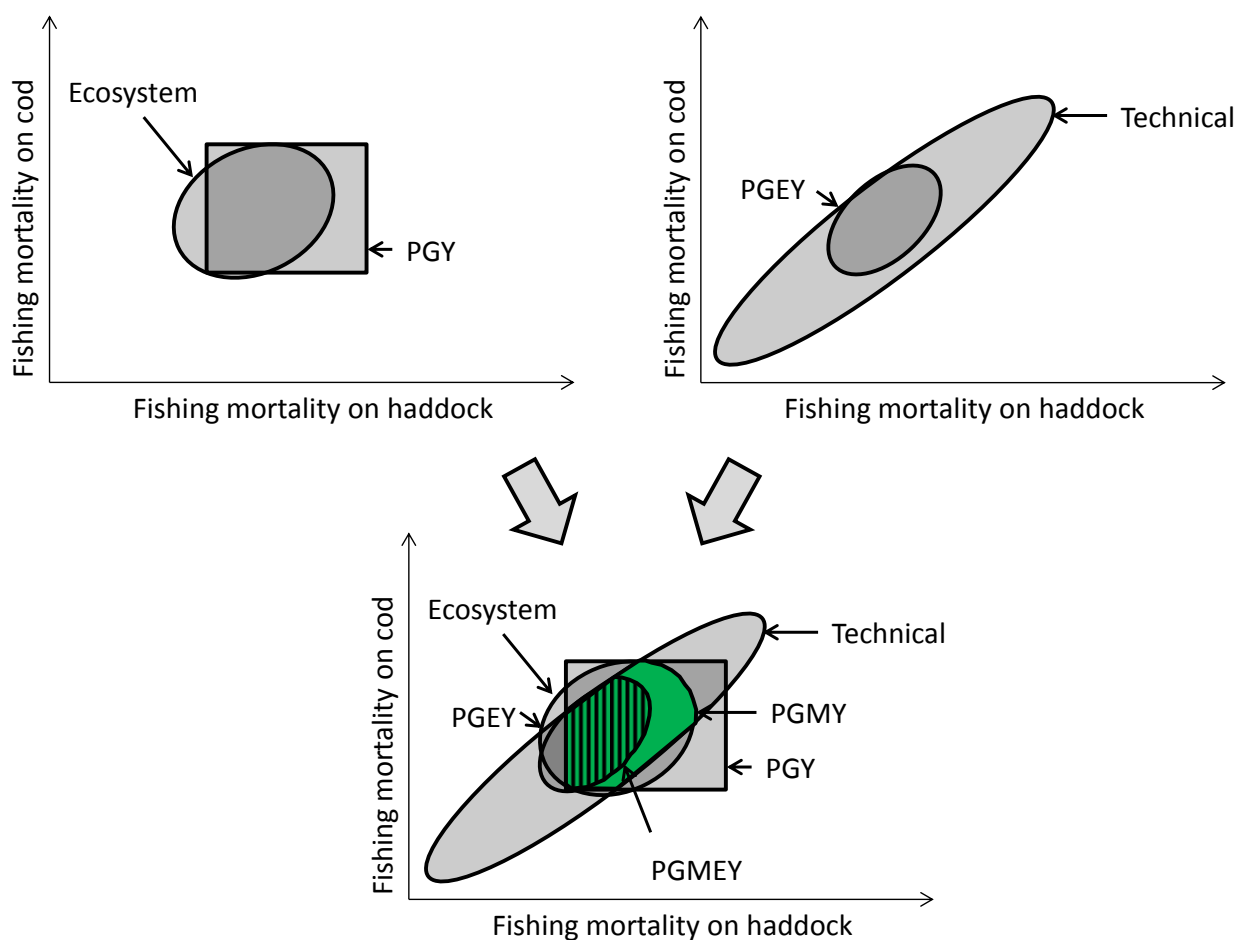
(ICES, 2015f) has developed one objective and generic **approach in a single-stock concept**, and used the **threshold of 5% loss of yield** as the basis for defining MSY ranges. But these values could be further refined to account for **other criteria of sustainability**: e.g. the **MSY F_{upper}** value could be lowered if other ecosystem considerations are included, or the **MSY F_{lower}** could be increased if **social** criteria are considered (Rindorf et al., in press, Figure 22). Also political constraints may forbid the usage of values above F_{MSY} in the longer run.

Following this approach, converting **ecosystem objectives** into corresponding single-stock F_{MSY} ranges may lead to a **narrower range**, for example keeping **98% of maximum yield instead of 95%**.

(ICES, 2015f) has also pointed out clearly that F values above F_{MSY} bear some costs in term of higher dependency on incoming year classes and higher variability in the advised catch opportunities (the occurrences where F has to be reduced because SSB is below MSY Btrigger will be more frequent). Fishing at the higher value of the range over a long period of time has negative consequences on fleets profitability and stocks biomass (although they might still remain precautionary with regards to B_{lim}). It may therefore not be appropriate to fish systematically and blindly at the upper range.

One transparent option might be for example to **choose F_{MSY} as the default option** for setting the **annual fishing opportunities**, and to allow for **deviation** from it within the range only on the basis of obvious and documented **short-term conflicts**, being of economic, ecological, social or political nature.

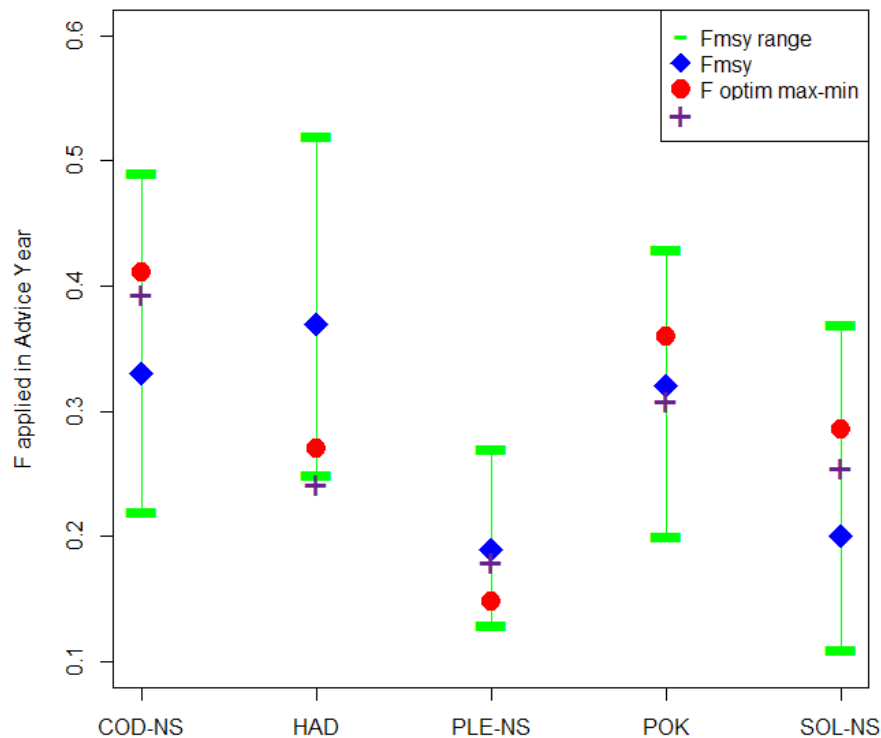
Figure 22. Hypothetical idea of a single-stock Pretty Good Yield, ecosystem- PGY and economic PGY for two groundfish species caught in a mixed fishery. Overlaps are displayed in green and striped green, indicating the most desirable areas of fishing mortalities for achieving multiple objectives.



Source: (Rindorf et al., 2016)

From there, **transparent options** might also be explored to choose the **management target** for the annual **TACs within the ranges**, i.e. to identify the **best** value of fishing mortality for each stock and each year. As one possible option, (Ulrich et al., submitted) have for example developed an optimisation algorithm aiming at **minimising the risk of over quota discarding in mixed-fisheries**, resulting in fishing mortality values intermediate between the $MSY F_{lower}$ and F_{upper} ranges (Figure 23):

Figure 23. Fishing mortality by stock in 2016: F_{MSY} , F_{MSY} ranges, F_{2014} and outcome of the optimisation algorithm



Source: (ICES, 2015e) and Ulrich et al., submitted

Ultimately, these are exploratory examples to illustrate that the concept of MSY ranges is **pragmatic** and potentially promising in a **mixed-fisheries context**, if used in a smart and measured way.

But this process is also still very **new** and needs to be fully understood. Much is still to be learnt and explored on how to make the **best use of ranges** and not blindly **manage stocks at the higher value**. The work needs to be pursued through an iterative and collaborative process involving scientists, managers and stakeholders.

5.4. Maintain institutional sustainability and reactivity

Over the last few years, a considerable debate has animated the scientific community worldwide, discussing the **true status of fish stocks** in developed and developing countries and arguing on the major drivers of when, why and how some fisheries are sustainable, and some are not (see for example (Pauly *et al.*, 2013) as well as the numerous other publications by these three authors). The main arguments by Professor Ray Hilborn (cf (Hilborn *et al.*, 2015) are that:

- **sustainability** is more **than ecological** sustainability. It also includes **economic growth and social development**. Different interests groups (large fishing industry, small-scale fisheries, environmental organisations, consumers, food processing industry etc) may thus use different criteria to assess whether a fishery is sustainable or not, and the same fish product may be deemed sustainable by one group and totally unsustainable by another one. But the legitimacy of each group's criteria is often questioned by other groups

- **Ultimately**, the most important factor of sustainability is not the actual objectives and criteria themselves, but the ability of the management institutions to take action and to implement ways to achieve them.

This factor can also be referred as “**institutional sustainability**” (Charles, 1994; Garcia *et al.*, 2003). It emphasizes the importance of having management authorities that are both proactive (setting clear goals) and reactive (adapting to changing conditions). An imperfect but adaptative path to manage fisheries could be potentially less risky than a blocked system where objectives and rules cannot be agreed upon.

5.5. Support the legitimacy of catch quota management

It has been described in section 3.4 how the **simultaneous** implementation of MSY and LO objectives may lead to vicious circles that could hamper their achievement, because of inappropriate economic incentives and poor industry support. Additionally, it has been shown in section 5 that the **actual ecological effects of removing** discarding are unclear and potentially limited, as are also the **ecological effects of bringing discarded biomass** to shore. It appears therefore that the most important aspect of the landing obligation is not so much the fate of discard after the catch, but mainly the ecological, economic and ethical benefits of avoiding catching them in the first place.

In this regard, **Catch Quota Management** is a more important mechanism than the actual **obligation to land**. For this, documentation is a primordial element. We argue that the most important necessity is to ensure that discards and unwanted catches are routinely estimated by fishers and reported in log-books. An **accurate reporting and monitoring of all catches** is a primary step towards sustainable and responsible fisheries. It may also incentivise more selective fishing by raising awareness of the extent of unwanted catches, regardless of the subsequent fate of discards. This priority should be enforced straight from the start of the policy implementation.

Ultimately, bringing discards to land requires changes **in handling practices on-board and at shore**, and while this shift is already emerging in a few places, this topic bears a great potential and will develop gradually, when **technologies and markets** become more available. Until then, it is felt that at present the idea of bringing discards to land is probably more contested by the fishing industry than the idea of Catch Quota itself, and a prioritisation of the implementation tasks during the transition phase 2016-2019 may improve the fishers’ perception of the policy’s legitimacy.

5.6. Be precautionary over the next five years

This final comment is to reflect on the **major uncertainties** regarding how the European fisheries will actually develop over the **next five years**. The 2013 CFP has set up very ambitious objectives, and the current European policy cannot be compared to any other fisheries in the world. As it has been explained in this report, there are many plausible scenarios for the future, some being more optimistic than others, but it is still too early to know which one(s) will dominate in the various fisheries. The situation of the North Sea demersal stocks is **rather positive at present**, and this is also reflected in significant increases in TACs in 2016. But globally, the European fishery system is **still not very resilient** yet. European fisheries have entered a state of fragile recovery, with many stocks **slowly improving** from **low biomass levels** and many fisheries slowly improving from low profitability and overcapacity levels (STECF 2015).

Therefore, **inappropriate management** decisions in the short-term may induce unbearable and potentially **irreversible damages**, and ruin the chances of achieving the CFP objectives. During the **gradual implementation of the landing obligation** between 2016 and 2019, many unknowns remain regarding, among others, **(i) the compliance** of the fleets, **(ii) the changes in behaviour** and in fishing patterns, and **(iii) the availability and the reliability of catch statistics** used in stock assessment. The effects of these unknowns will also likely not be perceived immediately, as it will take months or years before enough scientific evidence is collected on these. It would be appropriate to acknowledge these uncertainties, and act **precautionary** during the transition period. Adverse events such as major increases of fishing effort and fishing mortality should be avoided. Many commercial fish stocks in the **North Sea are already exploited at levels close to F_{MSY}** , which might indicate a better balance between the current fishing capacity and the productive potential of the North Sea stocks than has been the case in the previous decades. This better balance should thus rather be maintained. It may be wise to maintain the overall fisheries activities around the same level as they are now until full confidence is gained on the **controllability** and **enforcement level** of the landing obligation.

6. REFERENCES

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POLICY DEPARTMENT B: STRUCTURAL AND COHESION POLICIES

FISHERIES

The discard ban and its impact on the Maximum Sustainable Yield objective-The Atlantic Ocean: The Bay of Biscay case

Abstract

This report presents the most up-to-date status of the fishery modelling in the Bay of Biscay, in the Atlantic Ocean. Using both a qualitative and quantitative approach, we present an overview of likely effects of the maximum sustainable yield and the landing obligation policies on the ecosystem of the Bay of Biscay and the fleets exploiting the fisheries in this region.

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LIST OF ABBREVIATIONS

ACFM	Advisory Committee for Fisheries Management
BoB	Bay of Biscay
BRP	Biological Reference Points
B_{lim}	Limit reference point for spawning stock biomass (SSB)
B_{pa}	Precautionary reference point for spawning stock biomass (SSB)
B_{trigger}	Value of spawning stock biomass (SSB) that triggers a specific management action
CFP	Common Fisheries Policy
Choke Species	Species for which limited quota are available in a fishery, but which still would need to be landed
Discard	Part of the catch that is returned to sea
EAF	Ecosystem Approach to Fisheries
EBFM	Ecosystem Based Fisheries Management
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations
FM	Fisheries Management
F_{MSY}	Fishing mortality consistent with achieving Maximum Sustainable Yield (MSY)
GDP	Gross Domestic Product
GES	Good Environmental Status
GVA	Gross Value Added
ICCAT	International Commission for the Conservation of Atlantic Tunas
ICES	International Council for the Exploration of the Sea
IW	Iberian Waters
Landings	Part of the catch that is landed and sold
LO	Landing Obligation
Métier	A homogeneous subdivision of a fishery
MEY	Maximum Economic Yield
MSE	Management Strategy Evaluation
MSFD	Marine Strategy Framework Directive
MSY	Maximum Sustainable Yield. The largest average catch or yield that can continuously be taken from a stock under existing environmental

conditions

PGY Pretty Good Yield

Sliping When fish are caught in a net and subsequently released into the sea without being brought on board of the vessel.

SSB Spawning stock biomass. Total weight of all sexually mature fish in the stock

STECF Scientific Technical and Economic Committee for Fisheries

ToR Terms of Reference

TAC Total Allowable Catch

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EXECUTIVE SUMMARY

Background

The provisions of the reformed European Common Fisheries Policy (CFP) reflected in the Regulation (EU) No.1380/2013 set the stage for the fishery managers and stakeholders to take the initiative and responsibility for the implementation of their regional fishery management plans. To implement the provisions of the CFP, the discard ban and the MSY objectives, and to facilitate management by these parties, the relevant data needs to be obtained, accessed and deployed in a regional context, for the purpose of this research study, in the Atlantic Ocean, through the specific case-study of the Bay of Biscay. The Bay of Biscay fits into the southern region of the Northeast Atlantic and in effect runs the entire coastline of western France and Spain. Both the high productivity of this region coupled with its somewhat complex political and geographic structure make comprehension of the current fisheries a difficult task. As in many other fisheries in the Atlantic Ocean most of the demersal fisheries in the Bay of Biscay are composite, i.e. a given resource, composed of several stocks and exploited by various gears. Fishing can operate, according to the gear, the area or season, on different components of a population i.e. juveniles, adults. Overall the Bay of Biscay can be considered as a highly representative example of the existing complexity in the fisheries management of the Atlantic Ocean.

Aim

The aim of this study is to provide a summary report on the state-of-the-art scientific knowledge in the relevant fields and analyse the following topics:

- The current state of MSY modelling in the BoB as a case study of the Atlantic Ocean.
- A quantitative bioeconomic analysis based on a case study in the BoB of the likely consequences of the LO on the objectives of the CFP, especially the MSY.
- A qualitative and, if possible, quantitative assessment of the main effects of the LO, in the context of the MSY, on the whole ecosystem of the BoB.
- Recommendations on the best way to implement the discard plans and multiannual plans, following different scenarios at the regional level.

Main Findings

In the Bay of Biscay, the stocks for which **Maximum Sustainable Yield** is known are, in general, above the biomass reference point for which a further action is necessary (B_{trigger}). F_{MSY} , one of the benchmarks used to control different fishery aspects, is the fishing mortality that produces the maximum sustainable yield. However, the overall fishing mortalities in the Bay of Biscay are still above the F_{MSY} , the numerical target of the Maximum Sustainable Yield (MSY). Two-thirds of the landings come from stocks with an unknown stock status. This does not imply that there is not management at all, given that to these stocks with an unknown status the precautionary approach is applied. Since the year 2000 there are positive signals of the changing status of the stocks. However, individually, the number of stocks with an unknown status in the Bay of Biscay is too high. Procedures assessing the MSY principle need to be explored urgently, even if such an assessment provides only a limited overview ("something better than nothing" approach). These procedures can be based on the "data poor" approaches currently being investigated by for example the International Council for the Exploration of the Sea (ICES).

In the mixed fisheries (those with technical interactions between different gears) simultaneous management of some stocks at single-species F_{MSY} levels is likely to fail and create inconsistencies between the targets for the different stocks. These inconsistencies come from the technical interactions in the sense that the fleets catching different stocks and in some cases catching them simultaneously, cannot be selective enough to reach individual MSY of each stock, at the same time.

Fishing opportunities can be more easily reconciled and made consistent with the objectives of the Common Fisheries Policy by using the flexibility provided by the F_{MSY} ranges. However, adopting these ranges will increase the risk of overfishing if fishing is conducted persistently at the upper limit of the ranges. In any case, the scientific advisory process will have to be more focused on mixed and multispecies fisheries (fisheries in where many species contribute to the output) for a better management. This recommendation is reinforced by the introduction of the Landing obligation.

Landing obligation, introduced in the current Common Fisheries Policy, implies that catches of quota fish may no longer be discarded and that they have to be counted against the quota. Within the EU Atlantic waters it can be interpreted as a discard ban only for stocks subjects to TACs and quotas. In the Mediterranean it applies to species subject to minimum size limits. The Landing obligation (LO) generates the so-called choke effect (the smallest quota species in a mixed fishery: when the quota of such choke species is exhausted, the whole fishing activity has to stop). When landing obligation is combined with Harvest Control Rules (sets of well-defined rules that can be used for determining annual fish catch quotas) seeking a single-point estimate of MSY (i.e. F_{MSY}), the final fishing mortalities will be below the F_{MSY} . According to the MSY criteria, this constitutes a loss of fishing opportunities. However, this does not necessarily imply an economic effect, or at least not the same effect on all the fleets. Even though, in the short-term there will be economic (lower profits) and social (reduction in the number of vessels and hence of employment) losses, in the mid-term, some fleets will be better off. However, it is not possible to provide a clear long-term picture, especially because it is not easy to infer the likely consequences of the landing obligation in the ecosystem functioning. Exemptions (e.g. *de minimis*) and flexibilities (e.g. quota swap) effectively reduce the short-term effects of the LO. In the long term, the benefits of the LO implementation will also decrease using exemptions and flexibilities. The size of the exemption determines how close the system will be to the previous (no-LO) state. The higher the level of the exemption in the system, the closer it will be to the no-LO state.

The landing obligation will produce incentives for the fishers to reduce the discard levels. These incentives come in the form of fewer constraints for the fleet targeting one or more than one species (multispecies fisheries). There are many ways of reducing the discard levels; they depend on the spatial and temporal patterns of the fleet activity, including some fishing gear-related technical factors.

The overall ecosystem analysis does not give us precise results of the effects that the landing obligation will have on the Atlantic Ocean and in particular in the Bay of Biscay ecosystem. However, a preliminary quantitative analysis shows some differences between the results obtained for the no-LO and the LO scenarios. While both adult and juvenile hake biomasses are higher in the no-LO scenario, other species of the same guild (i.e., megrim) show different trends. Similarly, in the pelagic system, depending on the species, the management measures in each scenario have different effects: the landing obligation seems to be favourable for anchovy and horse mackerel, whereas sardine biomasses keep decreasing. The discard ban has negative effects on the carnivorous invertebrates such as Nephrops.

In the Bay of Biscay, few studies have assessed seabird attendance of the fishing vessels during fish discarding and few have shown the contribution of discards to the diet of populations or species. There is no study providing estimates of the discard consumption and contribution to the diet of the marine mammals, and there are no reports on the effect of discards on movement patterns, breeding success and adult survival.

The results of the preliminary analysis presented in this report show that there is no ideal solution for all the stocks. What might be a good solution for some species could have undesirable effects on other stocks. These results highlight the need for a holistic framework to find the most appropriate measures for the management of marine resources.

A discard ban must be accompanied by a suite of supplementary regulatory measures. We have learned that from the past attempts to analyse these complex systems. These measures could include **compensations for the extra work** of handling and processing the unwanted catch that now has to be landed. For example if this unwanted catch could be sold to the processing industry, all this extra income could go directly to the crew. It should also include a harmonisation between mesh sizes and minimum conservation reference sizes, considering also the commercial references, avoiding differences between different areas but equal markets that can confuse consumers. It should be also ensured that regulations are formulated to minimise possible incentives to discarding, for example allocating quotas to cover expected unavoidable bycatches. Finally this suite of supplementary regulatory measures should also consider the specific characteristics of some fleets like small coastal vessels fishing with passive gears, which have limitations in terms of mobility and ability to change fishing ground and hence to avoid some undesired catches.

Development and implementation of improved exclusive fishing technologies and operational methods could help to achieve a sustainable use of the marine resources. Some trade-offs need to be established to balance the effects of any intervention on the different components of the marine ecosystem.

In the context of implementation disturbances, MSY looks like a necessary target; however, MSY does not constitute in itself a plan. Any effective plan has to involve the ecosystem-based management. The existing uncertainties regarding the data and the system dynamics make the application of a multi-level ecosystem-based management a risky exercise. However, a plan following some well-considered steps might reduce those risks, or at least, it would be no more risky than the traditional fishery management.

Such a plan must be, of necessity, iterative and adaptive. Scientific investigation should be linked to a societal debate on management objectives, trade-offs, and analytical tools. No one individual can be fully aware of all activities and dependencies, so it is important to build teams working towards a shared regional vision, with a strong communication between the main players.

The plan must maximise the use of available information rather than emphasize the limiting impact of insufficient information and the lack of quantitative models on the application of the ecosystem approach. As we all know, it is unlikely that even a full understanding of the ecosystem would make the political decision-making easier. Furthermore, the complexities of governance should not be an excuse for avoiding new approaches. The society has the right to make decisions based on its evolving political processes.

There is room to achieve flexibility without sacrificing the sustainability of the fishing policy. The **Pretty Good Yield (PGY)** concept defined as the sustainable yield of at least 80% of the maximum sustainable yield could be mentioned as an example. Pretty Good Yield theory

acknowledges the fact that MSY (in the form of B_{MSY} or F_{MSY}) can either be treated as expected values (averages over time when fishing at a constant fishing rate) or point estimates given deterministic dynamics. Furthermore, by adopting a sustainable and “pretty” optimal solution, other uses and/or societal factors can be considered, without compromising the MSY concept. This flexibility is important to allow appropriate management. It also avoids the criticism that MSY has received from the very beginning, of ignoring the multispecies, multi-fleet of the fisheries. Single stock MSY concept requires that all species be exploited below their MSY abundance and therefore that the overall level of exploitation be fixed at the lowest level required by the species with the lowest resilience. Furthermore from the ecosystem perspective the MSY concept does not consider the existing relationships within all the ecosystem components. The flexibility provided by PGY can provide room for trade-offs between the economic and the social sustainability pillars.

This approach is also in line with the iterative and adaptive characteristics that any effective plan would need. The general policy and, in particular, the ecosystem-based fishery management have become a “predict and prescribe” strategy, exacerbated by the recent economic crisis in Europe and its social consequences. This probably reflects the limited research on the basic functions of the ecosystems. However, predictions have to be based on what we know and it is important not to base all our expectations on what might be a giant with feet of clay. Furthermore, the future is not likely to be a simple extrapolation of the recent past.

GENERAL INFORMATION

KEY FINDINGS for the Bay of Biscay

- The Bay of Biscay can be considered as a **representative example of the Atlantic Ocean**; it can also be treated as an individual ecosystem.
- The Bay of Biscay is an ecosystem fished by the fleets **from eight different member states**; the main two players are France and Spain.
- It is difficult to define a virgin/pristine ecosystem after centuries of anthropomorphic alterations. It is only possible to talk about the **ecosystem health** if we treat it as a unique organism.
- Ecosystem health is defined as a comprehensive, multiscale, dynamic and hierarchical measure of system resilience, organisation and vigour. All these concepts are embodied in the term "**sustainability**".
- The **ecosystem approach** serves multiple objectives, includes strong stakeholder participation and focuses on human behaviour as the central management dimension. The regionalisation of the advice is based on the ecosystem overviews in which the ecosystem state and pressures are summarized for the individual regions.

As in many other fisheries in the **Atlantic Ocean** most of the demersal fisheries in the Bay of Biscay are composite, i.e. a given resource, composed of several stocks and exploited by various gears. Fishing can operate, according to the gear, the area or season, on different components of a population i.e. juveniles, adults. Overall the Bay of Biscay can be considered as a highly representative example of the existing complexity in the fisheries management of the Atlantic Ocean.

The **Bay of Biscay (BoB)** has been suggested as an individual ecosystem by some sources, such as the Scientific, Technical and Economic Committee for Fisheries (STECF (2012)), while others (e.g., The International Council for the Exploration of the Sea, ICES) make it a part of the BoB and Iberian Seas Eco-Region. Both approaches can be easily supported. In this report, the BoB will be considered a manageable ecosystem composed by the ICES divisions VIII a, b, c and d (see Map 2 in Section 1 of this report).

The **ecosystem approach** serves multiple objectives, involves strong stakeholder participation and focuses on human behaviour as the central management dimension. However it is not easy to manage an ecosystem given that it is necessary to define its attributes. Setting up objectives is difficult given that we are trying to define a virgin/pristine ecosystem after centuries of anthropomorphic alterations. This is why if we treat it as a unique organism, in general, we talk about the ecosystem health.

Ecosystem health has been defined by Costanza (1992) as a comprehensive, multiscale, dynamic, hierarchical measure of system resilience, organisation and vigour. In fact, all these concepts are embodied in the term "sustainability". Sustainability implies the system ability to maintain its structure (organisation) and functions (vigour) in the face of external stress (resilience). The culture and attitudes of humans are the most important factors in our striving for sustainability. We can only achieve it by putting humans and their uses of space and resources at the heart of the decision-making process.

In this report we combine the ecosystem approach with the **regionalisation** given that the regionalisation of the advice is based on the ecosystem overviews, in which the ecosystem state and pressures are summarized by regions. The regionalisation is also supported by looking only at the fisheries. For example, according to Uhlmann et al. (2014), the region-by-region approach is preferable given the differences between the regional discard levels in Europe.

This report reviews the up-to-date information on the LO, its impact on MSY objective and on the ecosystem. It also provides an overview of the ecosystem processes to allow the ecosystem drivers to be incorporated into traditional fish stock assessments and formulate the operational advice. We discuss the data applicable to the BoB ecoregion.

We present a synthesis of the existing literature for ToR 1, a quantitative analysis based on the projections for ToR 2 and a combined analysis of these ToRs for ToR 3. ToR 4 presents the general conclusions and recommendations that can be extracted from ToRs 1 to 3. Some of the results, conclusions and recommendations could apply to all ecoregions outside the Atlantic Ocean. However, the report focuses on the main differences found from the comparison between the Atlantic Ocean (taking the Bay of Biscay as a case study) and other areas.

The area: the Bay of Biscay

The BoB is a gulf of the northeast Atlantic Ocean located south of the Celtic Sea. It lies along the western coast of France from Brest to the Spanish border and the northern coast of Spain to the Cape Ortegal. The average depth is 1744 m and the greatest depth is 4735 m. There is a continental shelf in the northern BoB, approximately 140-km wide, which becomes narrower to the south, reaching 50 km from the southern France. From the coast to offshore, the depth gradually increases to 200 m; the shelf is mainly flat. On the southern border of the BoB, the continental shelf of the Cantabrian Sea is as narrow as 12 km.

Map 1. Bay of Biscay

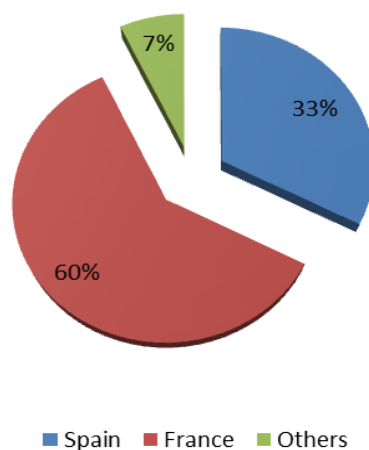


Source: AZTI

Fleets operating in the Bay of Biscay

The Bay of Biscay is an ecosystem fished by the fleets from different member states. According to the ICES database, eight member states report the catches: France, Spain, Germany, Denmark, United Kingdom, Ireland, the Netherlands and Portugal. In the year 2013, the first two countries (Figure) accounted for the 93% of the catches.

Figure 1. Catch composition by member state



Source: AZTI, using ICES data.

Table 5 provides a summary of the fleets of these two main member states. These fleets are subject to many different regulations, including effort regulations, technical regulations and a system of total allowable catches (TAC) and quotas.

Table 5. Main types of fleets in the Bay of Biscay.

Member State	Gear Type	Main Target species
France	Bottom trawls	Nephrops; Mixed: Sole, whiting, cuttlefish; Anglerfish
	Pelagic trawl small-mesh	Anchovy
	Pelagic trawl	Bass, Albacore
	Purse-seine	Sardine, anchovy
	Gillnets	Hake
	Gillnets large mesh	Anglerfish
	Miscellaneous	Crabs, bass, conger
Spain	Fixed nets	Hake, Anglerfish
	Longline	Hake, Great forkbeard, Conger
	Otter Trawl Mixed Fishery	Horse mackerel, Blue whiting, Mackerel, White fish
	Pair Bottom Trawl Fishery	Blue Whiting; hake
	Purse-seine	Sardine, anchovy
	Miscellaneous	Multispecies

Source: ICES

1. Summary of the current state of MSY modelling in the Bay of Biscay

KEY FINDINGS

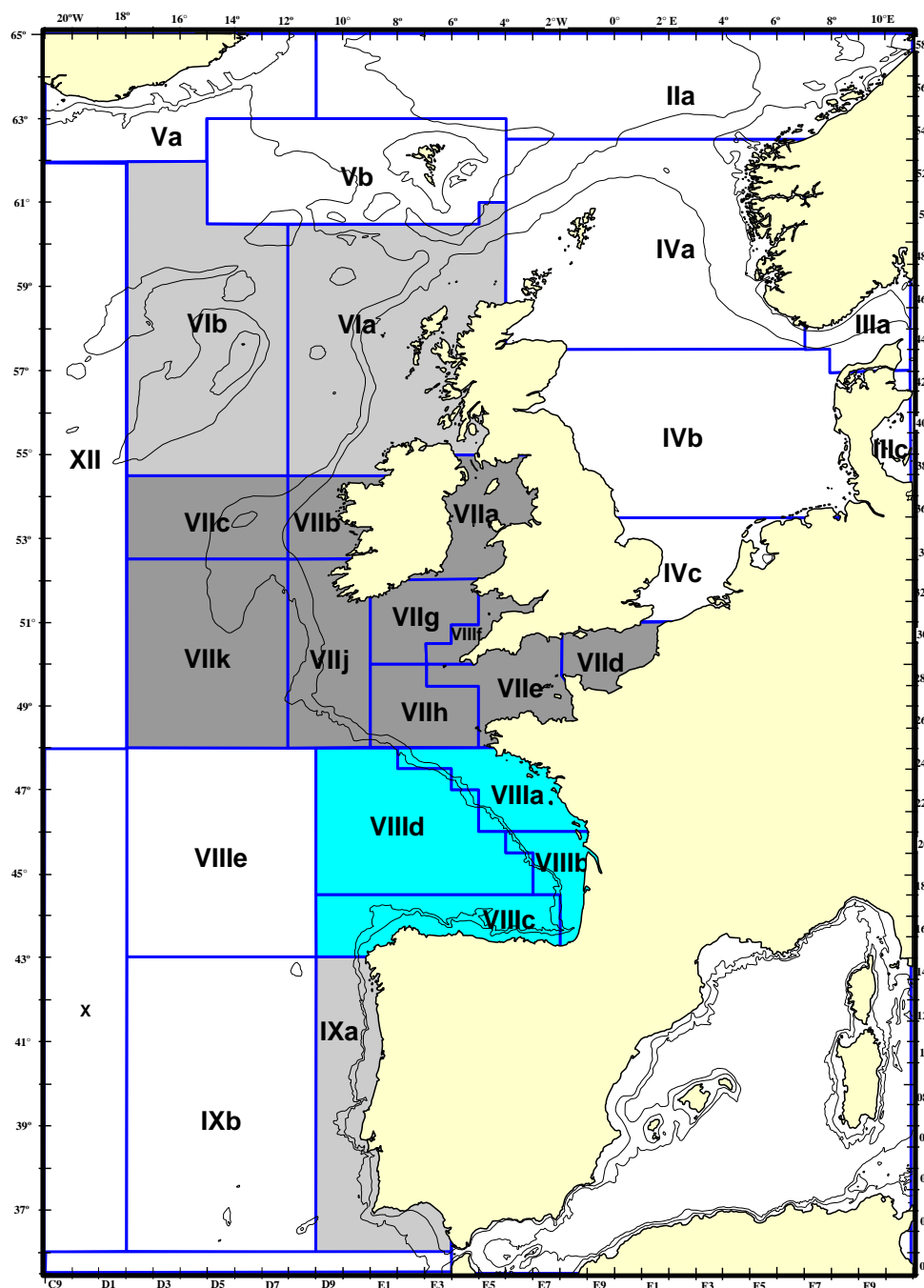
- The stocks with known MSY are in general **above the value of spawning stock biomass that triggers a specific management action** (B_{trigger}). For these stocks F_{MSY} seems to be a safe advice to reach the MSY objective.
- The number of species with an **unknown stock status** in the Bay of Biscay is too high (66%).
- The **impact** of the landing obligation in the Atlantic Ocean in general and in the Bay of Biscay in particular has not been fully evaluated.
- Managing many stocks at a single-species fishing mortality consistent with achieving Maximum Sustainable Yield (F_{MSY}) level is likely to create **inconsistencies** between the targets for different stocks. These inconsistencies come from the technical interactions in the sense that the fleets catching different stocks and in some cases catching them simultaneously, cannot be selective enough to reach individual MSY of each stock, at the same time
- Using **flexible targets**, such as ranges of MSY or multi-stock reference points, fishing opportunities can be more easily reconciled and become consistent with the objectives of the CFP.
- The use of flexible targets will increase the risk of overfishing if the fishing activities are maintained at the **upper limit** of the ranges.
- Fishing at the **lower limits** of the F_{MSY} ranges generate larger biomasses but lower catches and require less effort in comparison with the single estimate of F_{MSY} .
- The scientific advisory process should increase its focus on the **mixed and multispecies fisheries**. This recommendation is reinforced by the introduction of the landing obligation.

1.1. Modelling status

There are many large and diverse communities of the commercial species in the Bay of Biscay and the surrounding waters (ICES, 2014b). In the demersal species group, the most important commercial species are hake, megrim, anglerfish and sole. Cephalopods and rays are also considered target species by some fleets during some parts of the year.

The main pelagic species are sardine, anchovy, mackerel, horse mackerel and blue whiting. Seasonally, albacore can be found along the shelf break. Immature northern bluefin tuna migrate to the feeding areas in the innermost part of the BoB, from late spring to mid autumn, returning to the Gulf of Cadiz and Atlantic Moroccan coasts in winter (Rodríguez-Marín et al., 2007).

Map 2. ICES areas VI, VII, VIIIabcd and IXa. The Bay of Biscay is shadowed in light blue.



Source: AZTI

The study area is presented in the Map 1. For the purpose of this study, the BoB comprises the ICES divisions VIII a, b, c and d. Single stock scientific advice is made by the different regional fishery organisations, on the basis of the Biological Reference Points (BRPs). BRPs are the benchmarks with which the abundance of the stock or the exploitation rate can be compared. The stocks evaluated in the BoB waters and their statuses in the MSY approach are displayed in Table 6.

Table 6. Stocks for which there are reference points defined in the Bay of Biscay (BoB) and Iberian Waters (IW).

Stock	Distribution	F ₂₀₁₄ /F _{MSY}	SSB ₂₀₁₅ /B _{Trigger}
Sole (BoB)	Sole (<i>Solea solea</i>) in Divisions VIIIa,b (BoB)	Overfished	High risk of being overexploited
Hake (IW)	Hake (<i>Merluccius merluccius</i>) in Divisions VIIIc and IXa (Southern stock)	Overfished	Undefined
Four-spot megrim (IW)	Four-spot megrim (<i>Lepidorhombus boscii</i>) in Divisions VIIIc and IXa	Overfished	Small risk of being overexploited
Megrim (IW)	Megrim (<i>Lepidorhombus whiffiagonis</i>) in Divisions VIIIc and IXa	Overfished	Small risk of being overexploited
White anglerfish (IW)	White anglerfish (<i>Lophius piscatorius</i>) in Divisions VIIIc and IXa (Cantabrian Sea. Atlantic IW)	Overfished	Undefined
Black-bellied anglerfish (IW)	Black-bellied anglerfish (<i>Lophius budegassa</i>) in Divisions VIIIc and IXa (Cantabrian Sea. Atlantic IW)	Not Overfished	Small risk of being overexploited
Sardine in Divisions (IW)	Sardine (<i>Sardina pilchardus</i>) in Divisions VIIIc and IXa	Undefined	Undefined
Hake (BoB, Celtic Seas, North Sea, , English Channel)	Hake (<i>Merluccius merluccius</i>) in Division IIIa. Subareas IV. VI and VII and Divisions VIIIa.b.d (Northern stock)	Overfished	Small risk of being overexploited
Blue whiting (Combined stock)	Blue whiting (<i>Micromesistius poutassou</i>) in Subareas I-IX. XII and XIV (Combined stock)	Overfished	Small risk of being overexploited
Horse mackerel (Western stock)	Horse mackerel (<i>Trachurus trachurus</i>) in Divisions IIa. IVa. Vb. VIa. VIIa-c. e-k. VIII (Western stock)	Below 1	Small risk of being overexploited
Mackerel (Combined stock)	Mackerel (<i>Scomber scombrus</i>) in the Northeast Atlantic (combined Southern. Western and North Sea spawning components)	Overfished	Small risk of being overexploited
Boarfish (BoB, Celtic Seas, English Channel)	Boarfish (<i>Capros aper</i>) in Subareas VI-VIII (Celtic Seas and the English Channel. BoB)	Undefined	Undefined
Nephrops (BoB)	<i>Nephrops</i> in Divisions VIIIa,b (BoB, FUs 23–24)	Undefined	Undefined
Plaice (IW)	Plaice (<i>Pleuronectes platessa</i>) in	Undefined	Undefined

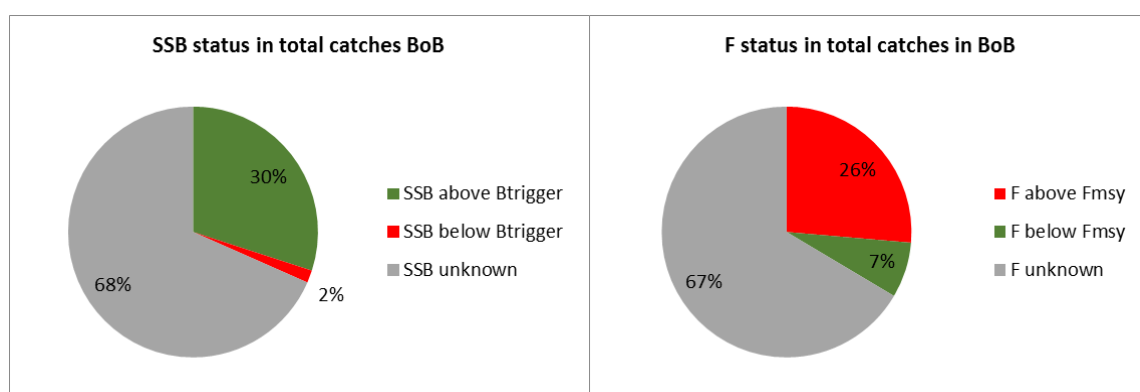
	Subarea VIII and Division IXa (BoB, Atlantic IW)		
Whiting (BoB, IW)	Whiting (<i>Merlangius merlangus</i>) in Subarea VIII and Division IXa (BoB, Atlantic IW)	Undefined	Undefined
Rays and skates		Unknown	Unknown
Saithe		Unknown	Unknown
Spurdog		Unknown	Unknown
Deep-sea sharks		Unknown	Unknown
Black scabbardfish		Unknown	Unknown
Alfonsinos		Unknown	Unknown
Roundnose grenadier		Unknown	Unknown
Orange roughy		Unknown	Unknown
Red seabream		Unknown	Unknown
Greater forkbeard		Unknown	Unknown

There are different approaches to the concept of MSY, using alternative reference points. F_{MSY} is the fishing mortality rate, which, if maintained, would result in MSY. Used as a biomass reference point, F_{MSY} can be seen as the implicit target harvest rate used to accomplish the CFP.

Table 6 defines three concepts:

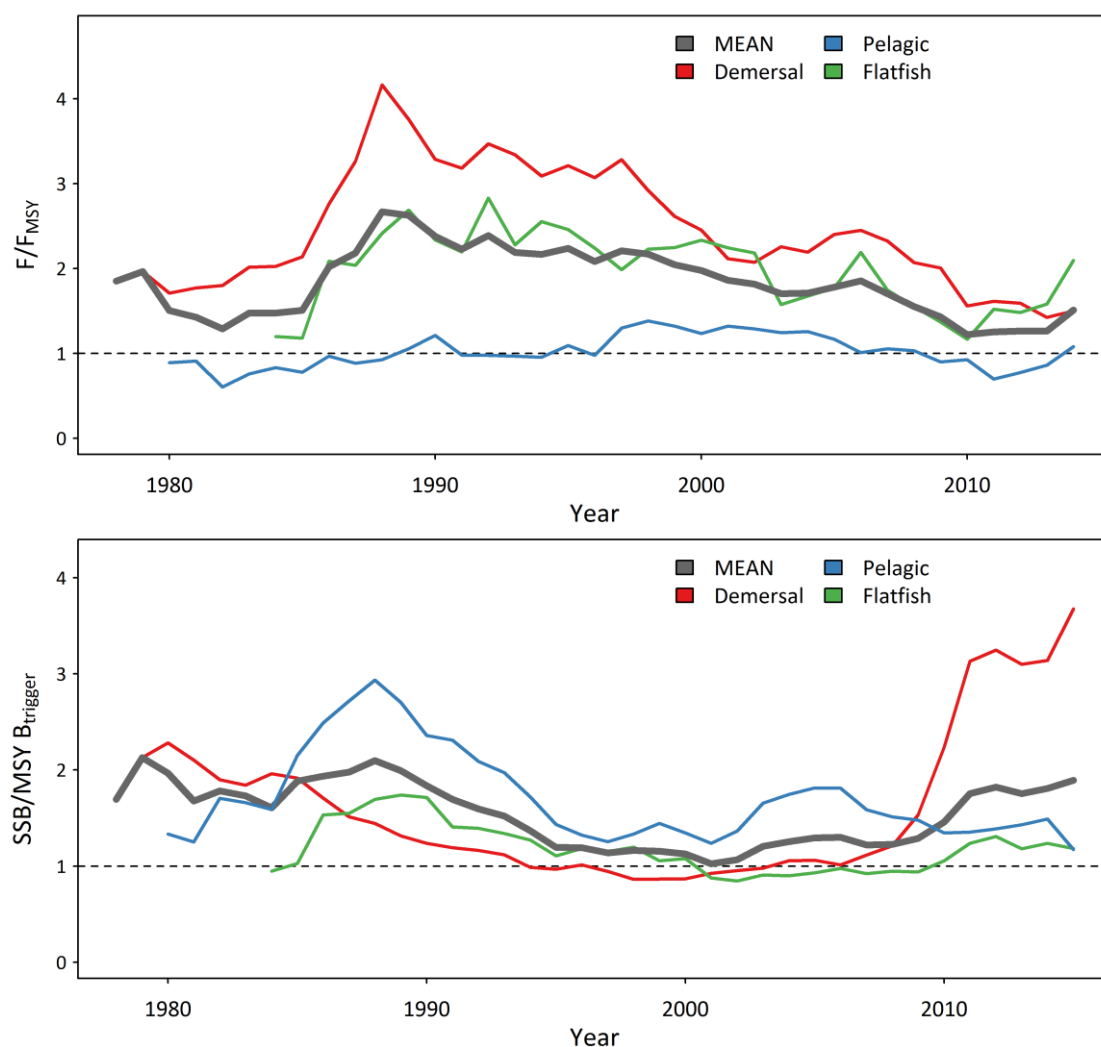
1. The ratio F to F_{MSY} . F is the *status quo* fishing mortality and F_{MSY} is the fishing mortality consistent with achieving the MSY. If the F value is smaller than the F_{MSY} , the stock is not overfished. If F is larger than the F_{MSY} , the stock is overfished.
2. The ratio SSB_{2015} to $B_{trigger}$. SSB_{2015} is the *statu quo* spawning-stock biomass and $B_{trigger}$ is the biomass level that triggers a specific management action. If the *statu quo* biomass SSB_{2015} is below the $B_{trigger}$, there is a risk of overexploitation; thus, some additional management action has to be taken apart from recommending the F_{MSY} . If SSB_{2015} is larger than the $B_{trigger}$, maintaining the F_{MSY} should safely accomplish the MSY objective.
3. There is a difference between the undefined and unknown situations. The situation is undefined if one or several reference points cannot be computed. It is unknown if only the landing estimates exist.

The overview of the stock status in the BoB is provided in Figure ; the stock status was multiplied by the landings in the BoB provided to the ICES (the year 2013).

Figure 2. Status of the stocks in the Bay of Biscay weighted by landings.

Source: AZTI

For the stocks for which reference points are known, the trend for the main groups of species (pelagics, demersals and flatfish) is provided by the ratio of F to F_{MSY} and the abundance (SSB) to $B_{trigger}$ (Figure).

Figure 3. Temporal evolution of the F to F_{MSY} (up) and SSB to $B_{trigger}$ ratios (down). The dotted line represents the ratio 1 that defines the overfished and risk of everexploitation, respectively

Source: ICES

Any impact assessment has to consider the multispecies and mixed fishery characteristics of the BoB. In a multispecies fishery, many species contribute to the output. Mixed fisheries are those with technical interactions between different gears. The Scientific, Technical and Economic Committee for Fisheries (STECF, 2015) has supplied the most up-to-date evaluation of MSY bioeconomic modelling considering the multispecies and mixed fisheries of the BoB. The report discussed the likely environmental, economic and social impact of a multiannual plan. It tested the MSY objectives and upper and lower limits of the stock within the framework of such a plan. That is, this work tested the likely effects of using fishing mortality ranges as an objective instead of single estimates. The exercise was fleet-oriented. The fleets were projected according to the best available knowledge of the dynamics of the stocks and their uncertainties. A summary of the results obtained in this work can be found in Section 1.2 of this document.

There are some other similar studies; however, they only cover some fleets or some stocks:

- The study of Guillen et al. (2013) has analysed the impact of exploitation using the MSY and the **maximum economic yield (MEY)** on the optimal effort allocation in fleets with different exploitation patterns and economic structures. The authors have shown that when the multi-fleet nature of the fisheries is taken into account, MSY landings are a third higher than the single-fleet estimates. It shows the importance of allocating fishing effort between fleets to obtain better yields taking into account joint production processes, various métiers and reallocation of effort (both in production and economic terms).
- The consequences of nonselective fishing operations have been analysed by Da Rocha et al. (2012). The authors report that the **single-species management objectives** might not be achievable in mixed fisheries. The practice could be unsafe for some species, promote over-quota discarding and lead to misreporting of the catches. The study reports the losses due to the use of the FMSY single-species target in the mixed fishery accounting for a tenth of the total discounted profit. This discounted profit is obtained multiplying anticipated profits to their current market value present value.
- Guillen et al. (2014) have explored the impact of the maximisation of catches or landings and the **effect of the survival level of discards on the MSY estimates**. They report that the optimal exploitation levels can vary significantly when optimizing for catches or landings and are affected by assuming a certain survival rate of the discards. All these factors can lead to different MSY target estimates.
- In the study of Morandeau et al. (2014), the **main reasons for discarding** have been identified using a sampling-based scheme. The results show that the main reasons for discarding are market-based first and quality-related, second. The regulation-associated factors have been less important in the analysed fisheries. The study has also shown that the decision to discard (live discards, in part) in highly selective fisheries might be motivated by the economic constraints.
- Da-Rocha et al. (2015) highlight the importance of the **discount factor** (associated with the projected value of the stocks). The discount factor is the multiplier that converts anticipated returns to their current market value (present value). That is, a positive discount factor implies that the present (catches, income, profits,...) is positively weighted in comparison with the future and that the higher this discount rate is the higher will be this positive weight of the present. They suggest that in the MSY computation, the discount factor should change depending on the scarcity of the resource.
- The studies by Garcia et al. (2016) and Prellezo et al. (under review) explore the likely **implications of the LOs in the context of the MSY**. They show that the multi-stock reference points, i.e., the computation of reference points per fishery (or at least for

the main stocks of a fishery) could reduce the negative impact of the LO. They also report that the LO provides an incentive to be more selective and reduce the level of discards.

- Guillen et al. (2015) have conducted an analysis of the **share remuneration system** (the crew paid a proportion of the value of the landings) for different stock and fleet objectives. The results confirm the necessity of stock recovery and improvements in the fleet efficiency to increase the salaries.

1.2. Summary of the results

Almost all the stocks for which **the MSY (or a proxy) is known** are above the biomass reference points for which a further action is necessary (B_{trigger}). However, the overall fishing mortalities are still above the F_{MSY} . It has been shown that two-thirds of the landings originate from the stocks with an unknown status. Since the year 2000, the ratio of F to F_{MSY} has been decreasing while the ratio of B to B_{trigger} has been increasing for the main group of species (demersal, pelagic and flatfish). In both cases, this is a positive development in the stock status.

We came across some important results in the existing literature. The result that the simultaneous management of several stocks at a single-species F_{MSY} level is likely to fail and create inconsistent targets for different stocks is of particular relevance. These inconsistencies are derived from the non-selective nature of the fishing gears. It implies that all the reference points cannot be obtained simultaneously at a given fishing effort level.

In the mixed fisheries, fishing opportunities can be reconciled and made consistent with the objectives of the CFP by exploiting the flexibility provided by the F_{MSY} ranges. However, adopting this approach will increase the risk of overfishing if the fishing activities are maintained at the upper limit of the ranges. If we take into account the mixed fishery requirements for matching the single-species targets simultaneously, the benefits of flexibility and adaptability might be lost. The probability of some stocks falling below $B_{\text{pa}}/B_{\text{lim}}$ reference points might increase and the economic performance could be impaired. Fishing at the lower limits of the F_{MSY} ranges generate larger SSB but lower catches and require less effort in comparison with the with the single estimate of F_{MSY} .

Last but not least, the conclusion of the STECF (2015) report is that the biomass safeguards for all stocks should still be maintained to provide a basic level of protection. These safeguards should guarantee that the SSB never (or with a low probability $<5\%$) falls below the B_{lim} (stock size below which there may be reduced recruitment). ICES stock estimates leads to a precautionary reference point B_{pa} , which is a biomass reference point designed have a low probability of being below B_{lim} . In most cases the safety margin is taken as a standard value, such that in most cases $B_{\text{pa}} = B_{\text{lim}} \times 1.4$. When the spawning stock size is estimated to be above B_{pa} , the probability of impaired recruitment is expected to be low.

Some **other important results** should be also highlighted:

-Inter-annual catch constraints should be kept to stabilize inter-annual fishing opportunities. In particular, it is necessary to consider the future discount factors, given that they affect the path to the targets.

-MSY estimates depend not only on the stock dynamics but also on the discard ratio and the discard survival rate.

-The reasons for discarding are diverse and the regulations are only one of the factors. In some fisheries of the Bay of Biscay, the economic constraints are more important than the

regulatory constraints. In that sense we can find market reasons which will be the case of highgrading) but also the additional costs of handling and storing unwanted or low valued fish.

-The implementation of the landing obligation will generate different effects, depending on the fleet. The overall results might be difficult to predict.

-Stock recovery and the improvements in the fleet efficiency are necessary to increase the salaries of the crew.

1.3. Summary of uncertainties and limitations

The data on the mixed and multispecies fisheries systems are still inadequate and do not allow a full evaluation of the risks associated with different management options. So far, not a single analysis incorporates all the fleets and stocks in the BoB in the same modelling framework.

The impact of the landing obligation in the BoB has not been fully evaluated. The reasons for this are diverse, but the main factor must be the uncertainty associated with the implementation of some of the measures. However, it has been shown that the concepts such as the F_{MSY} ranges are promising in terms of the flexibility they provide compared to the single point approach currently used for management references. Nevertheless, the implementations proposed in the STECF (STECF, 2015) are still provisional and not based on the approved ICES methodology. Furthermore, the risk associated with the use of these ranges has not been fully evaluated.

1.4. Summary of recommendations

The number of stocks with an unknown stock status in the Bay of Biscay is too high. Procedures to provide an assessment against the MSY principle should be urgently explored, even if they provide only a limited overview.

The scientific advisory process should concentrate more on the mixed and multispecies fisheries. This recommendation is reinforced by the introduction of the landing obligation.

STECF (STECF, 2015) advocates the use of harvest control rules (HCR) to avoid an additional level of uncertainty in the future decisions. A HCR represents a pre-agreed plan for adjusting management of a fish stock based on its perceived status. It implies that fishing possibilities are only driven by the natural variability of the fish and the management objectives in place, creating a stable environment to anticipate future fishing possibilities and hence the investment decisions of the fleets. Additionally to what the report of the STECF says we would also recommend defining the harvest control rules in the multispecies context, that is, harvest control rules have to consider and internalize the multispecies nature of the fisheries.

2. A quantitative bioeconomic analysis based on a BoB case study of the likely effects of the LO.

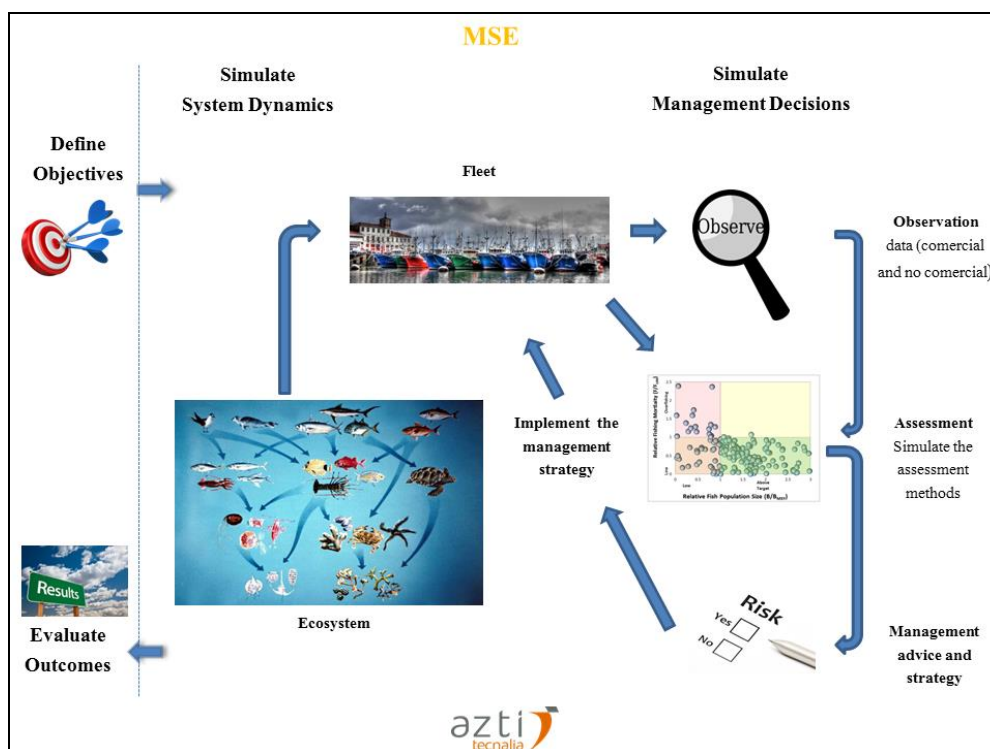
KEY FINDINGS

- In a multispecies context LO generates a **choke** effect; the real fishing mortalities of each individual stock will be below the FMSY calculated for this stock. In this context fishing (sustainable) opportunities are likely to be lost.
- The **incentives** to reduce the discards levels are produced by the necessity that the fleets have on trying to be not constrained in the effort that they can apply when targeting one or more than one species.
- There are many ways of **reducing** these **discard levels**, however all of them depend on the spatial and temporal changes in the fleet activity and the effort allocation, the technical factors (such as the selectivity of the fishing gear), etc.
- Real **fishing mortalities** should be below FMSY. Harvest control rules based on single-point estimates of fishing mortality can have this effect, at least in a multispecies context.
- Landing obligation and MSY are **two different objectives** of the CFP. Landing obligation cannot be considered as a direct mean to achieve MSY.

Quantitative analyses of fisheries are of growing importance given the necessity to assess the consequences of the future management actions. There are many models capable of dealing with this issue (Prellezo et al., 2012); however, they vary in their ability to build certain types of simulations.

An analysis of the likely effects of the LO is presented and discussed, based on a case study in the BoB. The simulation includes all the fleets involved in the catches of the northern stock of hake (*Merluccius merluccius*) and the Celtic Sea and BoB megrim (*L. whiffiagonis*). The analysis is conducted using a **bioeconomic simulation model** (FLBEIA) with the linked biological, economic and social dimensions. This implies that the economic results (mainly profits of the fleet, and the effort allocation to the métiers) affect the biological outcome (the catches made). The SSB and the fishing opportunities (TACs and quotas) also affect the economic results. Both factors will have a social impact depending on the contribution to the Gross Domestic Product (GDP) and/or the employment level.

In a simulation analysis, it is important to set a full **Management Strategy Evaluation** (MSE) cycle (Figure). MSE is a simulation-based methodology that is meant to identify harvest strategies with adequate, albeit potentially suboptimal, management performance with respect to multiple criteria over a wide range of model assumptions about the dynamics of the resources. This should be done, firstly, to complete the full feedback of the system, and secondly, to provide the scenario-based results presenting not the “the best” answer but the “what if” answer. The MSEs used for the management of fisheries can include a certain level of implementation uncertainty. They are designed for comparisons of performance and robustness of different management procedures rather than for the absolute risk estimates. Because of their feedback nature, such procedures allow at least partial adjustment of implementation errors, which is of great importance in a mixed fishery context.

Figure 4. Management Strategy Evaluation (MSE) cycle.

Source: AZTI

In our BoB case study, the definition of the problem (the data used and the dynamics included) is based on the simulations performed for the impact assessment of the multiannual management plan (STECF, 2015). However, instead of using MSY ranges, harvest control rules are used. The objective of these harvest control rules is to assess a target fishing mortality compatible with the MSY (F_{MSY}) unless the biomass falls below a certain level in which a further action is needed ($B_{trigger}$).

In a simulation model, many different **indicators** can be provided. However, the main, and probably the most robust, answers are those obtained using the following indicators:

- The evolution of the different biomasses by stock.
- The evolution of the fishing mortality and its comparison with the target fishing mortality (F_{MSY}).
- The total catches (including landings and discards).
- The Gross Value Added (the contribution of fishery to the Gross Domestic Product of the different member states).

Using these indicators, three different **comparisons** were performed:

1. The baseline scenario (LO scenario) versus the no-LO scenario. The baseline scenario applies the LO from 2018 onwards for all the subject stocks. Between 2015 and 2017, both options are equal. The option is designed to examine the effects of the landing obligation after 2018.
2. The baseline scenario versus the landing obligation scenario in which it is included the *de minimis* exemption (a flat rate of 5%).

3. The baseline scenario versus the landing obligation scenario in which it is included a year-transfer flexibility (a flat rate of 10%).

The CFP (EU, 2013) includes the landing obligation for commercial species with TACs and quotas. For stocks for which the ban enters into force before 2017, the ICES provides catch advice for 2016 on the assumption that the catches previously discarded will now be landed. To maintain a linkage to the past advice on catch and landings, the advised catches are split into 2 categories: a wanted catch and an unwanted catch. The wanted catch comprises the fish that would be landed in the absence of the landing obligation. The unwanted catch refers to the fish that had been previously discarded.

Within the **simulations** performed, the Article 15 of the CFP is covered in terms of implementation, exemptions (*de minimis*) in Section 2.2 of this report and flexibilities (year transfer) in Section 2.3 of this report. It is important to remember that there is another exemption, the high survival rate. This exemption has not been simulated because of the lack of information on its characteristics, except for Nephrops, and slipping (releasing fish before the net is fully taken on board if the catch is unwanted by the Skipper) for small pelagics in the BoB. The species transfer flexibility has not been considered either as it is not clear which species can be exchanged.

The simulations performed are stochastic, that is, the **uncertainty** has been explicitly modelled. In this case, the only modelled source of uncertainty is the stock-recruitment relationship (the relationship between parental stock size and the subsequent recruitment in numbers or the year class strength).

As uncertainty is a concept driving the management advice, it is important to understand how it is included. The study assumes that the recruitment provided by one stock size is not a single point (or a single vector) but a distribution. In other words we have the observed frequencies of occurrence of the values of a variable. This distribution is the result of a functional form (mathematically adequate) and the historical observations to fit this distribution (average value and a variance of the historical records). Instead of choosing the average value, we use any of the possible values that the recruitment can take. If we do it repeatedly (in this case, 250 times) we will obtain a distribution of the recruitment. This distribution will contribute later to the biomass, etc. This procedure allows a definition of risk levels, i.e., the number of times that these 250 iterations fall below a reference point (B_{lim}). If the result is zero, there will be no risk, and if it is positive, the risk will be positive.

We should note that:

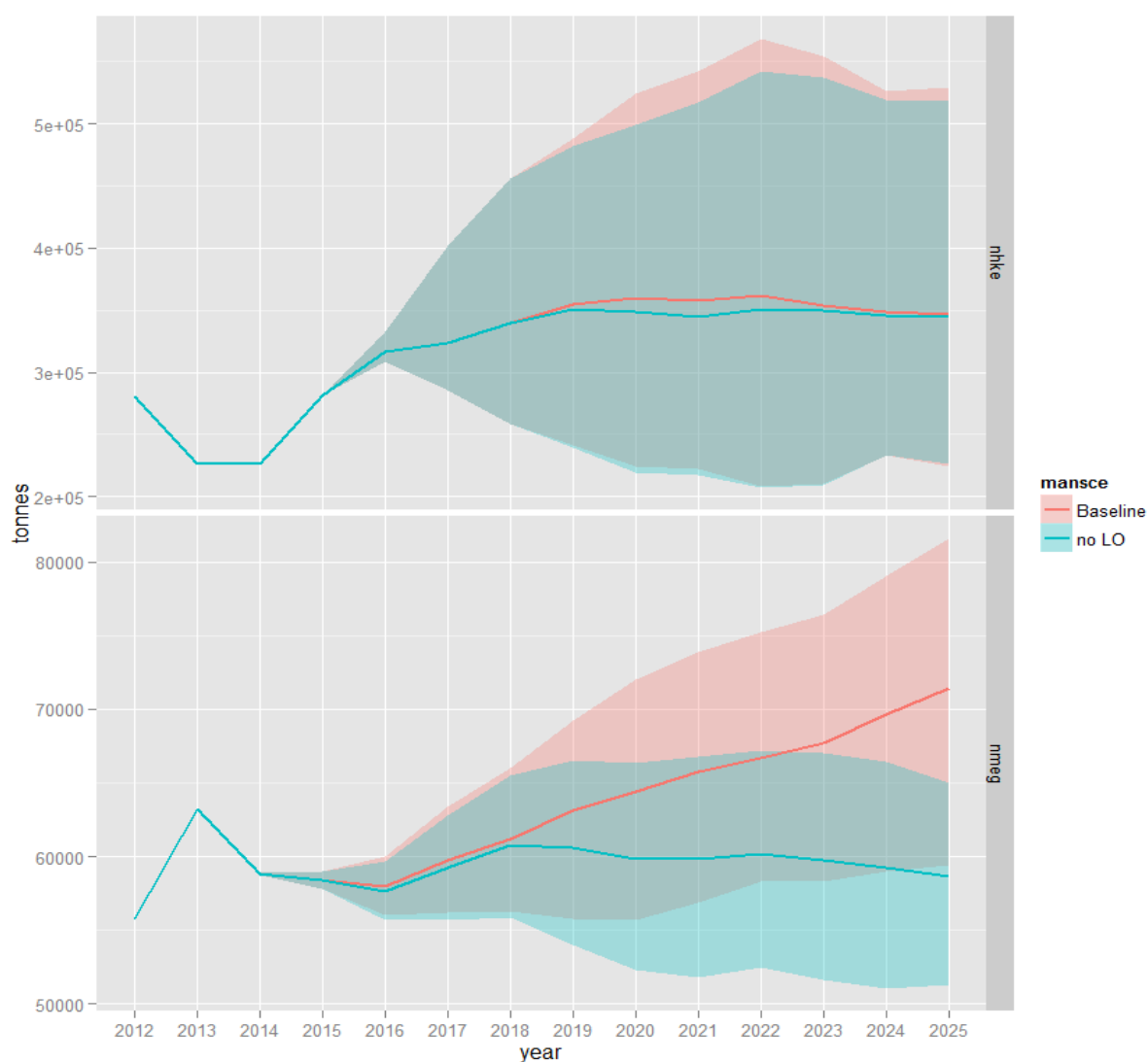
1. The results based on management strategy evaluation are not of a “what is best” but of a “what if” type. If the reference points are defined, it is possible to define risks and provide an average value with a risk associated for each simulated management strategy.
2. Any obtained risk value applies to the conditions under which the simulation is run, i.e., the limits, constraints and assumptions of the simulation (see Kraak et al. (2010) for further discussion of this issue).

2.1. The baseline scenario versus the no-LO scenario

In this section, we simulated the effects of implementing the LO in 2018 without any exemptions or flexibility. The year 2018 has been selected as the LO starting year in the STECF (2015) impact assessment. To be able to analyse the results of this complex action, the implementation should start simultaneously for all the stocks and fleets subject to LO.

Figure and Figure present the evolution of the SSB and F for two stocks, hake and megrim. Hake has an F_{MSY} set at 0.27. The Harvest Control Rule for the TACs is to advise F_{MSY} unless the biomass falls below a trigger biomass. If the biomass falls below this value, the F is proportionally reduced, so the biomass can recover. Another biomass reference point, the biomass limit, has to be considered as well. If the biomass falls below this limit, the advised TAC should be zero. We have no F_{MSY} for megrim; this implies that the advised TAC is based on the biomass trends. To check for trends, the latest biomass levels are compared to the previous ones. If there is a decrease of a 20% or more, the TAC is reduced by 15%. If the comparison shows an increase of more than 20%, the TAC is increased by 15%. For the values in the between, the TAC remains unchanged.

Figure 5. Biomass evolution for hake (up) and megrim (down) under LO (Baseline) and without LO (no-LO)



Source: AZTI

Figure 6. Fishing mortality evolution for hake (up) and megrim (down) under LO (Baseline) and without LO (no-LO). The horizontal line for hake is the F_{MSY} .



Source: AZTI

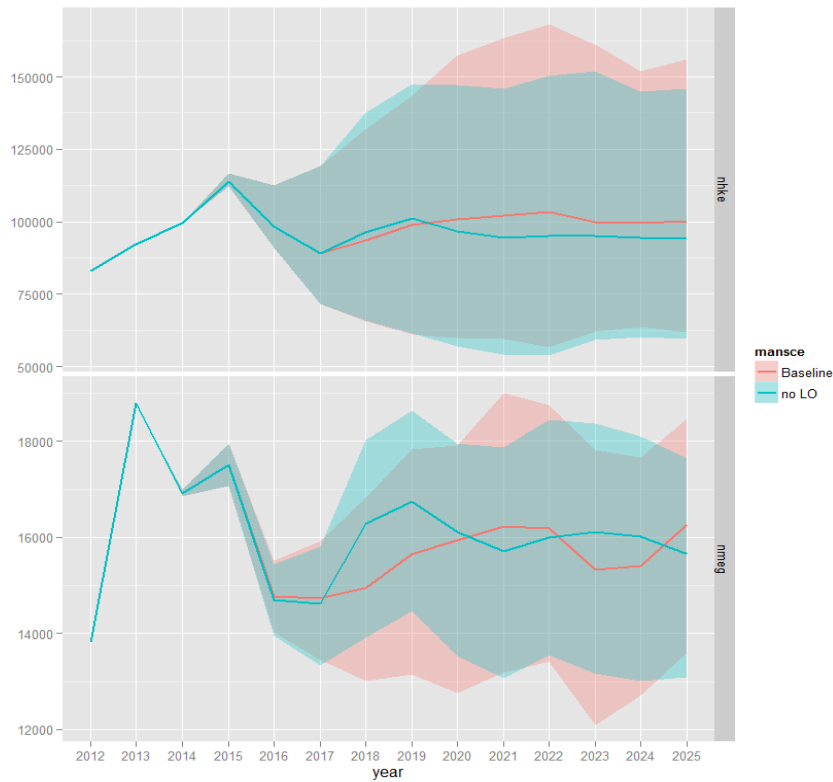
There are two important points to be noted in the analysis of the biomass and fishing mortality evolution:

- **Spawning stock biomass** is always higher with than without landing obligation. This is true for all stocks; however, the extent of this difference depends on whether the stock is a choke species (when the smallest quota in a mixed fishery, the choke species, is exhausted, the fishing has to stop) and for which fleet.
- **Fishing mortality** is always equal or less than F_{MSY} . This is a combined effect of the harvest control rule that try to advise F_{MSY} and the choke effect explained above.

We can conclude that:

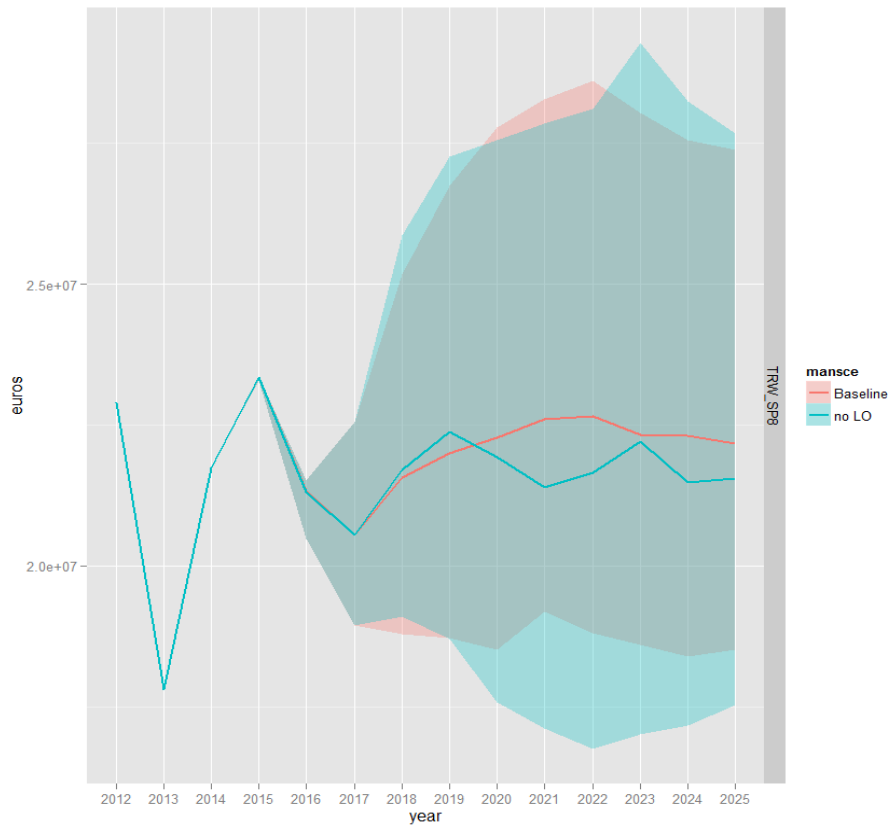
Some **fishing opportunities** are always lost under landing obligation; the final fishing mortalities are lower than the target fishing mortalities (at least for one species). However, this does not necessarily imply that the catches will be lower with landing obligation than without it. They will be reduced in the initial years of landing obligation implementation. However, as Spawning stock biomass increases with LO, the catches will increase too. Although the fishing opportunities are lost due to the choke effect, the biomass of some stocks might increase; after a few years, this extra abundance could be converted into more catches (Figure 30). This implies that there are fleets that, in the mid-term, could benefit from the landing obligation (Figure 31).

Figure 7. Catches for hake (up) and megrim (down) under LO (Baseline) and without LO (no-LO)



Source: AZTI

Figure 8. Gross value added created by one of the fleets of the BoB under LO (Baseline) and without LO (no-LO).



Source: AZTI

Under LO in a **multispecies, multi-fleet** context there will always be a choke species. This choke species will differ from fleet to fleet and it will limit the effort exerted by the fishery. In such cases, the fishing mortalities will decrease for all the stocks except for the one that produces this choke effect. Under such circumstances, advising F_{MSY} independently of the choke effect will lead to an increase in spawning stock biomasses (at least for a single-stock approach). However, it might reduce the fishing opportunities associated with the present single-stock MSY concept.

The short-term effects on the fleets are negative; no improvement in a biological system is instantaneous. Until the biomasses are substantially increased, the fishing efforts of the fleets will be reduced. This will result in lower landings and, consequently, lower profits.

However, in the mid-term, the picture is different. **The gross value added** from the fisheries is higher under landing obligation than without landing obligation, partly as crew remuneration (salaries) but also as capital remuneration (profit). Nevertheless, it is important to remark that even if the overall effect is positive, it will not be uniformly distributed; there will be some winners and some losers. However, determine which fleets will win and which fleets will lose is too case specific and depends on their likely reaction to the management in place.

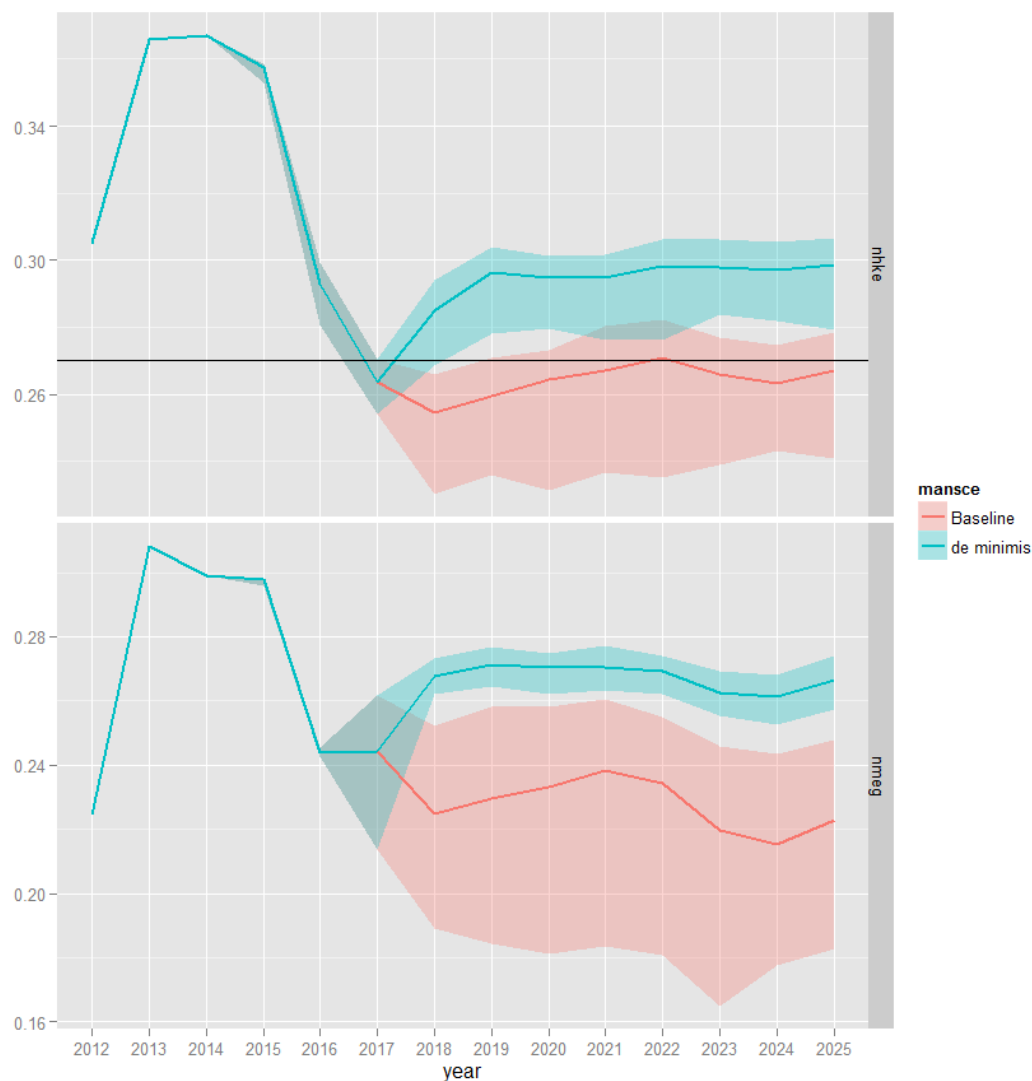
The discussion of the long-term effects requires a further ecosystem-based analysis (presented in Section 3 of this report).

2.2. The effect of the *de minimis* exemption

The CFP has anticipated some LO exemptions and flexibilities. The *de minimis* exemption allows the fleets to ask for a discard quota under certain circumstances (impossibility of selectivity improvement or a disproportionate increase in the cost of fish handling).

The main effect of this exemption is that the fishing mortality of the stock for which the exemption is granted will be higher than with the LO in place without any exemption (Figure 9). Total catches will increase as well, but not the total landings. This exemption is designed to reduce the effort constraint caused by the catches of individuals under minimum landing size. It might also reduce the effort constraint resulting from the previous over-quota discards.

Figure 9. Fishing mortality comparison between two landing obligation scenarios with (*de minimis*) and without (baseline) *de minimis* exemption.

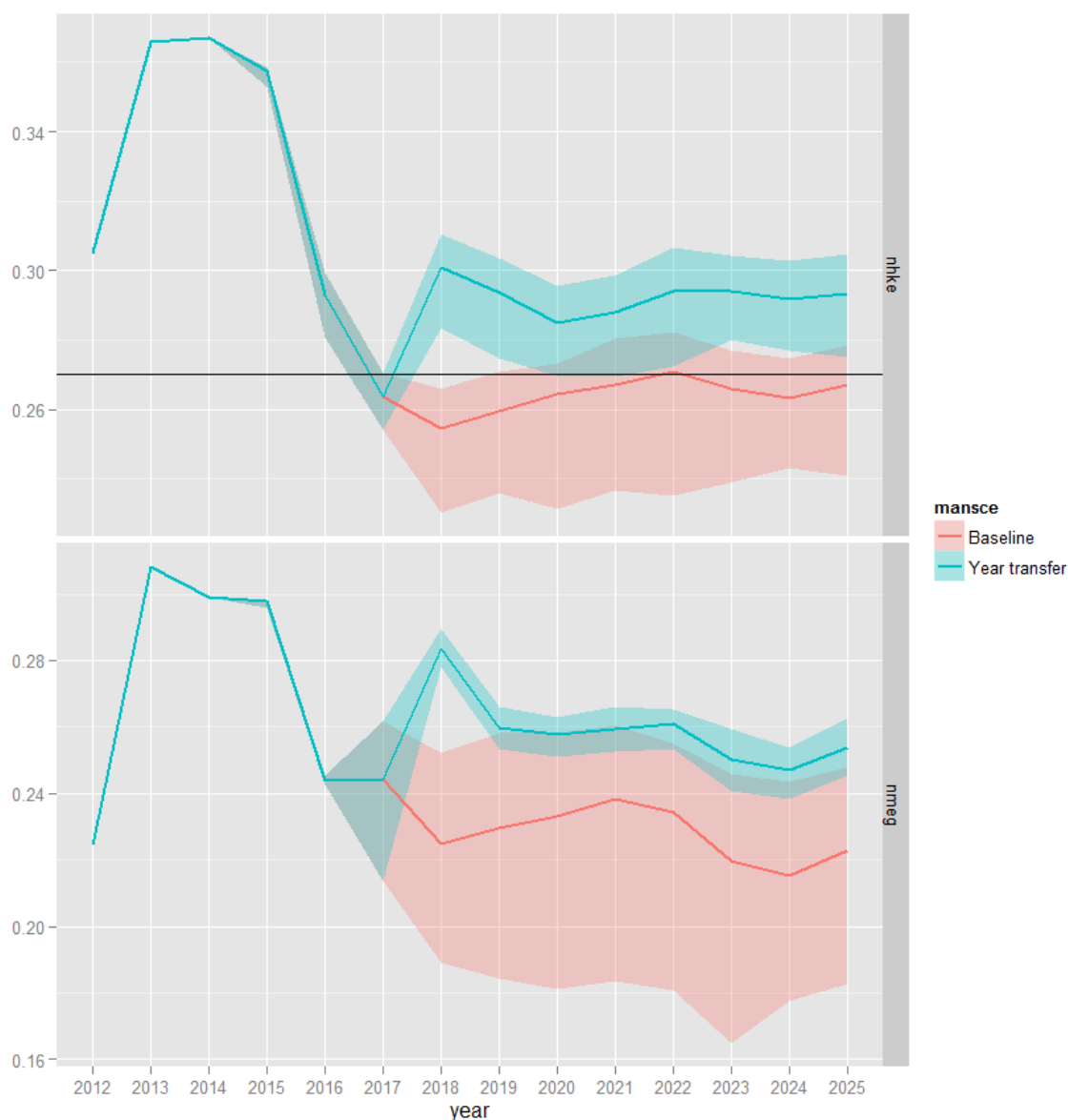


Source: AZTI

Figure 9 shows that, without *de minimis*, even when the harvest control rule for hake (nhake in Figure 9) means trying to reach the F_{MSY} , the real F is below this target in most years. However, the use of this exemption increases the value of F well above the target. This is caused by the fact that the *de minimis* exemption does not count against the TAC (at least in this simulation).

2.3. The effect of the year-transfer flexibility

Figure 10. Fishing mortality comparison between two landing obligation scenarios with (year transfer) and without (baseline) year transfer flexibility.



Source: AZTI

Year transfer (Figure 10) allows the use of the next year quota (up to 10%) but this extra quota used has to be subtracted from the next year catches. This flexibility promotes the landings of extra catches (*de minimis* promotes the discards). However, the negative side of the year transfer is that it concentrates almost all the flexibility in the first year of its use. After this first year, the catches have to be “returned”, and the effect of the year transfer after this first year becomes small. This does not necessarily imply that the total effect of the year transfer is small. As it can be seen in Figure 10 the year transfer always moves the fishing mortality beyond the target one, however this is an effect caused only by the first year in which is applied and given that in the rest of the year the transfer is compensated by the return of the precious year quota.

2.4. Summary of the results

Landing obligation generates **the choke effect**. If combined with an harvest control rule that seeks a single-point estimate of MSY (i.e. F_{MSY}), it will result in the final fishing mortality below the target fishing mortality (F_{MSY}). According to the MSY criteria, this will cause a loss of fishing opportunities, translating into a short-term economic loss. The size of this loss will depend on the characteristics of each fleet, the catch composition and the initial discard level. In the mid-term, some fleets will do better than others. However, the long-term effect is unknown as it is not clear how the ecosystems would respond.

Exemptions and flexibilities effectively reduce the short-term negative effects; however, the penalty to be paid in the long-term is that the benefits of the LO will also decrease. The size of the exemption determines how close the system will be to the previous (no-LO) state. With large exemptions, the system will remain close to no-LO state.

Incentives to reduce the discard levels are in place. These incentives come in the form of trying not to constrain the effort of a fleet targeting one or more than one species. There are many ways of reducing the discard levels, depending on the spatial or temporal activities of the fleet and the fishing gear technical changes made to improve the selectivity. In terms of technical measures it should be noted that not all of them have a relevant influence on reducing the constraints generated by the landing obligation (Alzorritz et al., 2016).

2.5. Summary of uncertainties and limitations

Many issues associated with the application of the landing obligation remain unclear. Thus, it is difficult to assess the consequences of the landing obligation and the MSY fully even excluding the ecosystem considerations. When the ecosystem factors are included (see Section 3), the system becomes even more difficult to analyse.

The analysis identified two main sources of uncertainties and limitations:

First, we have the current **single-stock assessment** and the subsequent single-stock reference and management points. This creates a contradiction between the aims (MSY) and the results (something lower than MSY). This is a contradiction not only in terms of implementation but also from a theoretical point of view. Assessments are provided based on single-species reference points even if an attempt to change it is underway. Obviously, the problem here is that the main interaction between the stocks (without considering the ecosystem) is technical, i.e., it is associated with the fleet. The fleet defines the final level of exploitation of the stocks. There are individual catch limits; however, the loss of fishing opportunities can erode the implementation of the CFP. The landing obligation is just an additional step, also causing losses of fishing opportunities, at least in the short and mid-term.

The second source of uncertainties is the fleet itself. It is difficult to predict **how the fleets will react**. However, given the incentives in place, we can expect a reaction. Some positive changes are likely to be driven by the landing obligation, such as alterations in the fishing patterns to diminish the choke effect. We can anticipate that there will be changes in fishing gear technology and/or re-allocation of effort in the spatial and temporal dimensions). However, these reactions are not straightforward to simulate as the research on the fleet behaviour in the BoB is still in its infancy. It implies that the extent and intensity of these (likely) changes are difficult to predict.

On the other hand an aspect that has not been analysed in this report but that can play an important role is the aspect of the **recreational fisheries**. In the Bay of Biscay, and according to Zarauz et al. (2015), removal by the recreational fishery of Sea bass account for approximately the 40% of the total catches. Furthermore according to the same sources removals of *Sparidae* and Cephalopods, even if not clearly quantified, are also of high importance for the evolution of these species.

2.6. Summary of recommendations

The results discussed here come from an analysis of a model, and any model is based on several assumptions. Thus, it is better to interpret these results in relative terms rather than in absolute terms by keeping in mind the assumptions under which these data are valid.

Under an **Harvest Control Rule** that forces the system to reach a target fishing mortality (F_{MSY}), the landing obligation produces the effect of turning targets into limits. Real fishing mortalities of almost all the stocks will be below F_{MSY} , and hence this target fishing mortalities will only be seen as limits that can be crossed. Harvest control rules based on single-point estimates of fishing mortality have this effect, at least in a multispecies context. In this context, the concepts of (1) **multi-stock reference points** (Da Rocha et al., 2012), (2) **Pretty Good Yield** (Hilborn, 2011) or (3) **a combination of the two**, are building up a significant momentum.

It has been obtained the result that the “choke” species could **differ from fleet to fleet**. This implies that part of this problem could be mitigated by:

- A redistribution of the quotas that each member state has.
- By a quota swapping between member states.

Both actions would create a better balance between the catches and the quota composition by fleet, reducing the choke effect.

3. A QUALITATIVE AND QUANTITATIVE ASSESSMENT OF THE MAIN EFFECTS OF THE LANDING OBLIGATION IN THE CONTEXT OF THE MSY IN THE WHOLE ECOSYSTEM OF THE BOB

KEY FINDINGS

- A discard ban must be accompanied by a **suite of supplementary regulatory measures**. These measures should harmonize fishing technics, biological reference values, and markets. They should also ensure that regulations do not disincentive the reduction of discarding and consider the specific characteristics of some fleets.
- Since the marine ecosystems are very complex, any changes in the way they are exploited might have several **unpredictable consequences** from a single-species perspective.
- Ecosystem based fisheries management is the ideal framework to advise on the potential **effects of human activities** on the marine ecosystems.
- Seabirds take an extensive advantage of discards and the availability of such fishery waste can affect their life-history traits and population dynamics, as well as the community structure.
- In the Bay of Biscay there is no information on the effect of discards on the life-history characteristics of **marine mammals**, such as breeding output and adult survival.

An ecosystem can be considered a community of interacting living and non-living elements. The living elements constitute the biotic features, and the non-living objects are the abiotic features. While ecosystems do have boundaries, these are not always clear, and it may be difficult to decide where one ecosystem ends and another begins.

Managing fisheries considering an ecosystem approach is sometimes considered a constraint in the short-term development. It has been seen as a trade-off of short-term sacrifices for long-term gains. However, the ecosystem approach gives us an opportunity to look at all dimensions of the problem. It should help us find the management solutions based on the coordinated action of society, at several different levels.

There is a myth of the extreme complexity of implementing the ecosystem approach in the fisheries (Patrick and Link, 2015); some authors consider it naïve to even consider such a goal (Prellezo and Curtin, 2015). It is important to remark that, while it might be difficult, there are different levels of ecosystem approach and, in particular, of **ecosystem-based management**:

It is important to define the classical **fishery management** (FM) concept as a benchmark. FM is focused on a single sector (fisheries), where the fish stock is evaluated by a single specific stock assessment. The main objective of FM is to delineate the status of a stock and its productivity, identify adequate levels of productivity and evaluate within-stock effects of fishing. Its main output is the so-called reference points.

In the **ecosystem approach to fisheries** (EAF), in some cases, the multiple-stock integrated assessments are conducted to identify the levels of optimal stock production, cognizant of the ecosystem factors, and evaluate the within-stock effects of the multiple potential drivers of this change. However, the output is the same: stock reference points.

A further step is the **Ecosystem-based Fisheries Management (EBFM)**. Conducted in the same sector (fisheries), the evaluation process is based on integrated ecosystem assessments. The objectives differ from FM or EAF; the trade-off identification is included. The output is also different; it provides systemic reference points.

The **Ecosystem-based Management (EBM)** includes all the sectors (and not only fisheries); unlike in EBFM, the trade-offs are identified across sectors.

The CFP defines the ecosystem-based approach to fisheries management as "...an integrated approach to managing fisheries within ecologically meaningful boundaries which seeks to manage the use of natural resources, taking account of fishing and other human activities, while preserving both the biological wealth and the biological processes necessary to safeguard the composition, structure and functioning of the habitats of the ecosystem affected, by taking into account the knowledge and uncertainties regarding biotic, abiotic and human components of ecosystems" (EU, 2013). This definition assumes substantial benefits from the aquatic resources while the direct and indirect effects of fishing operations on marine ecosystems are limited and not detrimental to their future functioning, diversity and integrity.

The CFP definition merges the ecosystem approach to fisheries and the ecosystem based fisheries management. This EBFM is meant to contribute to the good environmental status (GES) (EC, 2010) in conformity with the Marine Strategy Framework Directive (MSFD) adopted in 2008 (EC, 2008), in which the fisheries are considered a descriptor and a pressure.

This is not the only definition of such approaches. In the ICES, the ecosystem approach has been defined as a management regime that maintains the health of the ecosystem while allowing the appropriate human exploitation of the environment, for the benefit of current and future generations. Thus, the ecosystem approach is expected to achieve long-term sustainability of the exploited marine resources (e.g., the fishery sector).

Even before the "Rio Declaration" of 1992 (UN, 1992), the **dangers** of applying MSY concept to ecosystems were known (May et al., 1979). Walters et al. (2005) have explicitly stated that there is a risk of extinction of some species if MSY is applied to ecosystems carelessly. Any EBM implementation has to consider the existing relationships between the ecosystem components. MSY does not do it, and the advice provided might be misleading (Pauly et al., 1998). In contrast, it has been shown that EBFM can be achieved by improving the current single-species management (Mace, 2001; Froese et al., 2008). Several studies (e.g., Zhou et al. (2010)) suggest that substantial reductions in fishing mortality (caused by fishing) should be considered to meet all the EBM requirements. These include multispecies interactions, maintenance of genetic diversity and reduction of waste and discards. Single-species models might provide the same advice (reductions in fishing mortality) for different reasons.

If both recommendations are valid, the change from considering ecosystem a "black box" to a **holistic approach** where the ecosystem is the starting point in any analysis might seem a paradigm shift. Nevertheless, as pointed out by Mace (2001), the advice is a continuum representing both extremes. To advocate that both extremes should be represented in the final advice might be the right answer, but even so, the intermediate solutions must also be considered.

Different international **regulations limiting discards** have been implemented in the recent years, as a result of public opinion campaigns to limit the discards considered a waste of living resources (Hall and Mainprize (2005) and Bellido et al. (2011)).

The compulsory landing of discards introduced by the European Union (EU, 2013) will have consequences at the fleet and stock level (see Section 2) but also at the environmental-ecological level. To minimize the impact of fisheries on the wider ecosystem, some selective fishing practices have been encouraged. These practices should reduce the bycatch and discards which, apart from target-species juveniles, mainly affect non-target species (Zhou et al., 2010). However, it is not clear whether the highly selective fishing is beneficial for the ecosystem (Bundy et al., 2005), if it supports the sustainability of fisheries (Garcia et al., 2012), and who should bear the financial consequences (Garcia et al., 2011). Nevertheless, selectivity is not an explicit aspect of the management tools.

3.1. Potential effect of the LO on the BoB ecosystem: a qualitative approach

As other exploited systems, most fisheries have existed for decades in the BoB, affecting the whole ecosystem and contributing to its status. The fishery operations, which shift the nutrition and energy from the ocean to land and between depths or locations, cause habitat modification and return the unusable nutrition to the ocean. Reducing discards may not be always beneficial. It might affect the ecosystem negatively, at least in the short-term, in against the objectives of EBFM. The BoB ecosystem is **a bottom-up controlled system**, with a detritus-based biomass input control and high energy transfer efficiencies (Lassalle et al., 2011; 2012). These characteristics increase the sensitivity of this ecosystem to fishing activities; thus, any changes that affect the fishing practices need to be carefully considered.

The consequences of the LO are expected to be more apparent in the short-term, whereas a new equilibrium point should be achieved in the long-term. It should result in the desired changes in the structure and functioning of the BoB ecosystem (Tsagarakis et al., 2013) and benefit its health (Tett et al., 2013). These changes should lead to improvements in the goods and services offered to the society (Rapport et al., 1998).

The discards might be deposited dead or alive (Suuronen, 2005), with different consequences. The direct effects of continuing this practice at the existing or reduced levels are not fully understood (Diamond and Beukers-Stewart, 2011); (Lindeboom and De Groot, 1998). The live discards, indirectly affecting the whole systems through cascading effects, are expected to have the biggest impact (Heath et al., 2014b). Eliminating the live discards means preventing the return to the sea of live individuals that might still play their roles in the system. This might affect the highly diverse systems such as the BoB and the Iberian coast (Suuronen and Erikson, 2010; Sardà et al., 2013). However, the negative changes could be alleviated by the improvements in the health of the stocks affected by the discard regulation. The system might become more productive under a decreased fishing pressure (Diamond and Beukers-Stewart, 2011). The direct effect of the discard ban on the recovery of the stocks has not been assessed yet. However, the implementation of such regulations in other ecosystem different from the BoB (Norwegian Sea and Barents Sea ecosystems) has actually improved the estimated fishing mortality. This might have helped to make effective management decisions and is likely to have contributed strongly to the recovery of the fish stocks (Diamond and Beukers-Stewart, 2011).

The table below (Table 7) lists the general effects of eliminating discards cited in the literature, for an ideal situation where any other factor (i.e., fishermen behaviour or gear technologies used) changes. The main effects and mechanisms have been summarized at different biological organisation levels.

Table 3. Potential effects of the full implementation of the landing obligation at different biological organisation levels.

Biological organisation	Main Mechanisms	Potential effect(s) of Landing Obligation	Ecosystem component(s) /properties	References
Population level	Individuals that could potentially return back alive to the system will no longer be available in the system.	Increases in species mortality	Species with high survival rate ¹⁴	(Depestele et al., 2014); (Suuronen, 2005); (Suuronen and Erikson, 2010)
	Reduction in biomass leads to reduction in natural mortality and intra-specific competition.	Increase in species productivity	Larval and juvenile stages of species with high survival rate	(Quinn and Deriso, 1999); (Zhou, 2008)
	Removing fraction of adults leads to a shift in the age distribution to younger and then faster growing individuals.	Increase in species productivity	Targeted species	(Quinn and Deriso, 1999); (Zhou, 2008)
		Increases in mean weight and length at catch in the long-term	Target species	(Gullestad et al., 2015)
	Fleet land larger proportion of small fish and smaller proportions of large fish	Improves stock recovery rates	Overexploited or threatened stocks	(Diamond and Beukers-Stewart, 2011)
Community level	Died individuals or individuals with less survival rate will not return to the system	Reduce availability of 'easy food' ¹⁵	Benthic invertebrates	(Bozzano and Sardà, 2002); (Harris and Huang, 2001)
			Fish	(Bozzano and Sardà, 2002); (Heath et al., 2014b)
			Turtles	(Tomas et al., 2001)
			Mammals	(Lassalle et al., 2012); (Heath et al., 2014b)
			Birds	(Bicknell et al., 2013); (Heath et al., 2014b); (Votier et al., 2013)
	Reduction of energy (discards) impacts the resilience of an exploited ecosystem	Reduce secondary production and nutrient recycling	Plankton	(Coll et al., 2008); (Heath et al., 2014a); (Libralato et al., 2008); (Sardà et al., 2013)

¹⁴ Mainly invertebrates and small fish¹⁵ Discards that return death to the system

Ecosystem level	Reduction of species productivity lies on reduction of total system productivity	Changes in system productivity	Structure and functions	(Hall et al., 2000); (Zhou, 2008)
	Reduction of energy (discards) impacts the resilience of an exploited ecosystem	Trophic cascades: bottom-up and top-down effects	Structure and functions	(Heath et al., 2014b) Sardà et al., (2013)
	Changes in the availability of species	Changes in predator-prey relationships	Structure and functions	(Zhou, 2008); (Coll et al., 2008); (Tsagarakis et al., 2013)
	Increases in some species fishing mortality	Changes in biodiversity: richness, evenness, mean trophic level (MTL)	Structure and functions	(Sardà et al., 2013); (Worm et al., 2006); (Zhou, 2008)
		Redirecting energy flows and pathways	Structure and functions	(Hall et al., 2000); (Murawski, 2000); (Roux et al., 2013); (Worm et al., 2006)
	Discards will never reach the benthic system	Break benthic-pelagic systems coupling	Structure and functions	(Tsagarakis et al., 2013)
	Fleet land larger proportion of small fish and smaller proportions of large fish	Changes in MTL of the catches	Fleet – humans	(Coll et al., 2008) (Diamond and Beukers-Stewart, 2011)
	Total reduction of discards will be sometimes not feasible nor desirable	Reduce the greatest benefits possible from fisheries resources to society in the short-term	Fleet – humans	(Diamond and Beukers-Stewart, 2011); (Pascoe, 1997); (Zhou, 2008)

The marine ecosystems are complex, with many interactions between their abiotic and biotic components. They are also affected by human activities. Thus, any actual or potential changes should be carefully analysed using a holistic and integrative approach. In the case of fisheries, the EBFM would be the ideal framework to manage these problems.

3.2. Potential effects of the Landing Obligation on the Bay of Biscay top predators: a qualitative approach

The marine predators interact with commercial fisheries in various ways (Arcos et al., 2008). The fishing activity can affect marine predators directly through mortality caused by entanglement in fishing gear (i.e., bycatch) and ship strikes (marine mammals) (Lewison et al., 2004). These animals can also be indirectly affected by changes in the distribution, abundance, size structure and behaviour of their natural prey (Arcos et al., 2008). In addition, fishing activity provides an unnatural source of food to the scavenging predators. Bottom trawling, one of the fishing activities providing large amounts of discards, affects the food sources of the demersal species (Hudson and Furness, 1988).

The focus of this section is not an assessment of predator direct mortality, but rather **the revision of the effect that a decrease in discards as food subsidy** (due to the progressive ban) might have on marine predator populations (both seabirds and marine mammals, particularly for cetaceans). Whenever information was available, a special mention was provided for the Bay of Biscay.

Seabirds take an extensive advantage of discards and the availability of such waste can affect their life-history traits and population dynamics, as well as the community structure (Votier et al., 2004). Indeed, the discards provide an important food source for scavenging species, possibly changing their movement patterns (Bartumeus et al., 2010; Bodey et al., 2014). The discards substantially contribute to the diet of these birds (Navarro et al., 2009), improve their reproductive performance (Oro et al., 1996; Louzao et al., 2006) and increase their survival (Oro and Furness, 2002; Oro et al., 2004). Consequently, this human-introduced food resource might favour more generalist species, sustaining their increasing populations (Furness, 2003). In the BoB, few studies have examined seabird attendance of the vessels discarding fish. A few reports have shown that discards are part of the diet of certain populations and species, e.g., yellow-legged gulls (Arizaga et al., 2010).

There are no studies estimating the discard consumption by **the marine mammals** and no reports on the effect of discards on movement patterns, breeding success and adult survival. There are some studies showing that cetaceans follow different fishing gears such as purse-seiners, trawlers and longliners. They consume the commercial target species and, therefore, directly compete for the same resource. In the Bay of Biscay, Spitz et al. (2013) have studied a dietary overlap between common dolphins and sea bass (*Dicentrarchus labrax*), which might be associated with the bycatch of common dolphins by pelagic trawlers. However, it is unclear whether the life-history traits of marine mammals, such as breeding output and adult survival, are affected by the discards.

Anticipating the effect that the discard ban might have **on marine predator populations** is a challenging task. A recent review performed by Bicknell et al. (2013) highlighted the potential consequences of discard reform for seabird communities. However, we have not found such a review for marine mammals. While the role of discards for seabirds has been long studied and there is an overall understanding of the population-level effects (Bicknell et al., 2013), the same does not apply for marine mammal populations. This is partially due to the ease of conducting seabird population monitoring (i.e., land-based) compared to cetaceans and therefore obtaining information on the foraging ecology, at-sea distribution patterns and life history traits (e.g., breeding output and adult survival).

For **seabirds**, the effects of discard decrease can affect predator populations directly through behaviour, diet (i.e., prey switching) and distribution patterns at sea (Bicknell et al., 2013). At the population level, demographic parameters such as breeding output and survival could be

affected (Bicknell et al., 2013). In European waters, the seabird scavenger community is composed mainly by a relatively small number of large generalist taxa (Bicknell et al., 2013). In the absence of discards, some of these species might be able feed on alternative food resources by increasing predation on other seabird species or occupying new habitats, and increasing seabird bycatch (Bicknell et al., 2013). Some of the potential positive effects could be a decrease in numbers of the dominant generalist species (Bicknell et al., 2013). However, we are still missing the community-wide understanding to foresee how the most vulnerable species (i.e., with limited foraging plasticity) could be more affected by a decrease of discards to the more generalist omnivorous species.

Alternatively, anticipating the effect that the discard ban might have **on marine predator** populations could be assessed using ecosystem models. Studies from the North Sea marine ecosystem show that landing the entire catch while fishing as usual has negative effects for marine predators, while the combination of landing obligation with more efficient fishing practices (i.e., limit the capture of unwanted fish) could benefit predator populations (Heath et al., 2014a). In the Bay of Biscay, an ecosystem model was modified to specifically tackle fisheries impact on the main cetacean species considering both landings and discards (Lassalle et al., 2012). Therefore, it would be possible to perform simulation studies to compare different discard availability scenarios to understand the effects of discard banning on cetacean populations. For seabirds, it would be necessary to increase the number of compartments to incorporate the most abundant and vulnerable species.

3.3. A first attempt to handle discarding problems from an ecosystem perspective in the Bay of Biscay: a quantitative approach

Although the importance of moving towards **the EBFM** is widely recognized, so far, very few studies have been conducted in the BoB. Furthermore, none of them deals with the problem of discards or the effects of the implementation of the LO in that ecosystem. A forthcoming study focusing on discards (Andonegi and Prellezo, In preparation) analyses the effects of the fisheries on the ecosystem of the BoB. **The study shows how the combined effects of the discard ban could modify the dynamics of the studied system.**

A substantial effort has been put into the modelling in this area, involving both the existing environmental interactions and the dynamics of the stocks (Andonegi et al., 2011). The trophic relationships between relevant commercial species (Saavedra et al., 2015; Andonegi et al., 2009) have been analysed as examples of EAF. Several other studies have dealt with the food-web dynamics of the BoB French Continental Shelf ecosystem from an EBFM perspective. Some other examples can be found in the reports by Lassalle et al. (2011; 2012; 2014), Chaalali et al. (2015) and Bentorcha et al. (*In press*), though none of them is dealing with discards specifically.

Some effort has been made towards the **implementation of integrative quantitative tools in the EBM** in the BoB, in parallel with those described above. However, this is described in a work in progress and has not been published yet. One such case is the **Nested Environmental State Assessment Tool (NEAT)** being developed under the DEVOTES EU project¹⁶, expected to be available at the beginning of the next year (2016). Some work has been undertaken on a global scale using the **Ocean Health Index** (Halpern et al., 2012). A similar exercise, using more accurate local information, has been carried out for some of the regions in the BoB. There are also a few studies dealing with the implementation of Atlantis ecosystem model, which assesses all the human activities in the BoB. This model is used in the development of adaptive management tools helping the scientific community to provide the appropriate advice to the managers. Finally, it is worth mentioning a qualitative framework

¹⁶ www.devotes-project.eu

developed within the ODEMM EU project¹⁷, which is used in the implementation of integrated ecosystem assessments (Levin et al., 2009) in the BoB within ICES (ICES, 2013, 2015). Similar new developments are being utilised in the DEVOTES project (work in progress).

This section will focus on the EBFM, and some preliminary results from the work of Andonegi & Prellezo (in preparation) are shown. In this study, the authors analyse the **potential changes in the ecosystem dynamics**, using a food-web model constructed employing Ecopath with Ecosim software, version 6.4.(Christensen and Walters, 2004; Christensen et al., 2008).

An **Ecopath model** has been built for the year 1996, simulating the status of the French Continental Shelf ecosystem at the end of last century. The model consists of 35 functional groups from the detritus and plankton to the marine mammals and seabirds. These functional groups are single-species groups or bulk species with the same characteristics; only one of them (hake) has a life history stage with a complex feeding strategy. Four fishing fleets have been included to cover the majority of the fishing activity in the area. Temporal simulations have been run for the years from 1996 to 2013 using the time-dynamic module **of Ecosim**. Different scenarios have been projected once the historical part of the model (1996-2013) was parameterised by fitting to the available time series. The authors have used information on landings and discards of the Spanish fleet from a local (AZTI) database. These data have been combined with the data reported by the different member states to ICES. Some information has been taken also from the existing models (Lassalle et al., 2011) and from other sources, including the FishBase database¹⁸ (Froese and Pauly, 2015).

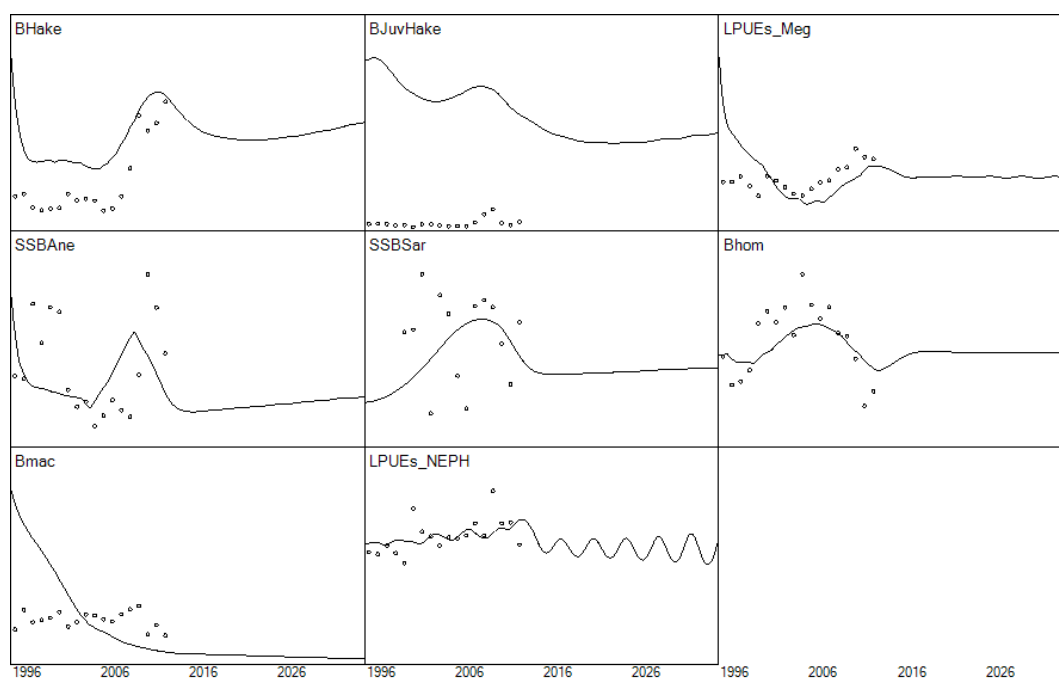
Some preliminary results have been obtained from the Ecosim run (Figure, Figure), once the model has been parameterised by fitting it to the available time series (biomass, fishing mortalities and fishing efforts).

Two different **scenarios** have been projected to analyse the changes in the system. One combines the MSY with the landing obligation where all catches need to be landed (LO Scenario). The second scenario, the MSY one, it is based on forcing the system to reach F_{MSY} levels (No-LO). However, the MSY reference points have been set only for a few of the species, such as hake and blue whiting; the remaining functional groups have been forced with a historical average fishing mortality (the mean of the last three years). In the landing obligation scenario, hake and megrim, the species managed under a TAC system and affected by this regulation, are forced to different fishing mortality values obtained from the simulations detailed in Section 3 of this report.

¹⁷ <https://www.liverpool.ac.uk/odemmm/>

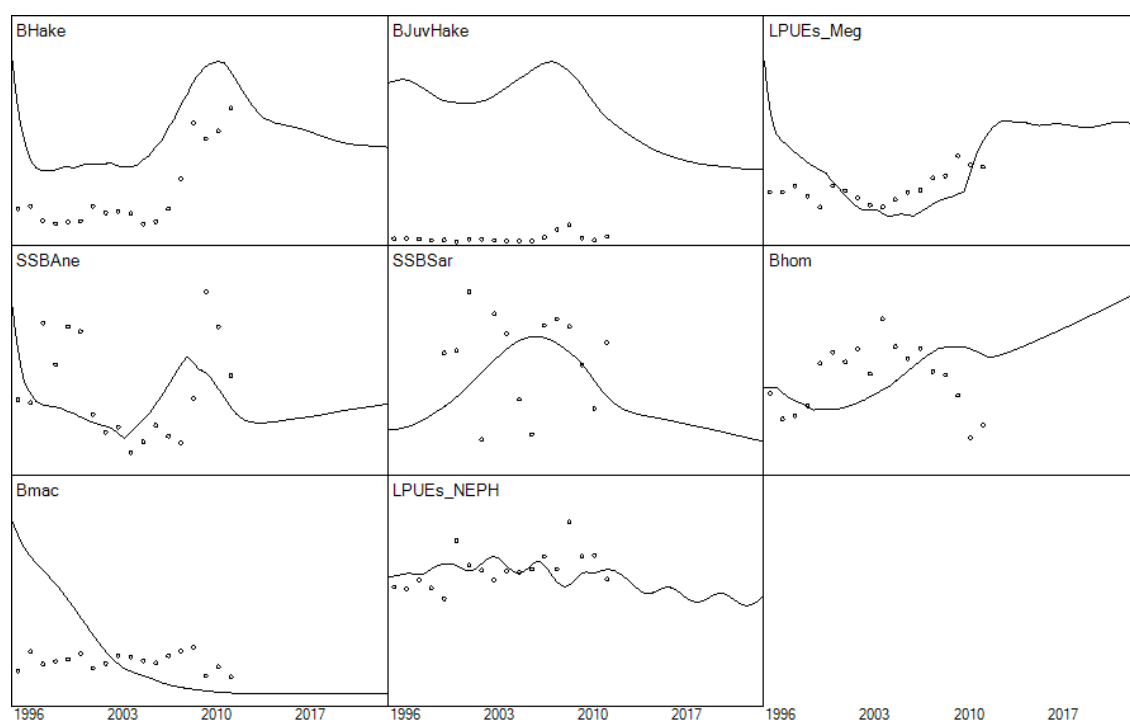
¹⁸ www.fishbase.org

Figure 11. Modelled (lines) and observed (dots) biomasses for commercially relevant species (from left to right: adult and juvenile hake, megrim, anchovy, sardine, horse mackerel, mackerel and nephrops) in the Bay of Biscay – The MSY no-LO approach.



Source: AZTI

Figure 12. Modelled (lines) and observed (dots) biomasses for commercially relevant species (from left to right: adult and juvenile hake, megrim, anchovy, sardine, horse mackerel, mackerel and nephrops) in the Bay of Biscay – The MSY LO approach.



Source: AZTI

3.4. Summary of the results

There are some differences between the results obtained from **the no-LO and LO scenario** analyses. While both adult and juvenile hake biomasses were higher in the no-LO than in the LO scenario, other species of the same guild (e.g., megrim) showed different trends. This also happened in the pelagic system, where, depending on the species, the management of each scenario caused different effects. The LO benefited anchovy and horse mackerel, whereas the sardine biomasses kept decreasing. Similarly, the discard ban seemed to have a negative effect on the carnivorous invertebrates such as *Nephrops*.

Even though the results presented here are preliminary, they demonstrate that there is no ideal solution for all the stocks. What seems **a good solution for some species might be undesirable for other stocks**. This highlights the need for the holistic frameworks to find the most appropriate measures for the management of marine resources.

3.5. Summary of uncertainties and limitations

There are many assumptions in this work. Most of these assumptions had to be made because the spatial resolution of the available information did not exactly match the area studied (BoB) in this exercise. The distribution of most of the species included in the model exceeds the study area and there is no accurate information about the distribution of the individuals. **The data** coming from **stock assessments and observations** on landings and discards are not spatially explicit either, which hampers this type of study.

The pedigree (or quality) of this analysis is expected to improve once the scientific survey data are introduced for tuning the biomasses simulated by the model. We hope that this is going to happen in the near future.

The Ecosim application presented for the BoB is only dealing with the top-down effects caused by fishing. However, some bottom-up disturbances might arise if the environmental conditions were considered. This might lead to changes in the dynamics of low trophic level species such as small pelagics and could alleviate the impact of the top-down cascading effects.

The knowledge of the intra- and inter-species relationships is another key factor in this kind analysis. Currently, this knowledge is limited or not publicly accessible; such data would greatly help in obtaining reliable and “close-to-reality” results.

An inclusion of **social and economic information** in the discussed frameworks would also be beneficial. The MSEs from the ecosystem perspective are crucial and should be developed in the near future.

In order to assess the impact of discard bans, it is necessary to obtain **information** on the **foraging ecology**, at-sea distribution and abundance patterns, and population-level demographic parameters. That is not currently available for many marine mammals (Lassalle et al., 2012). Even for seabirds, we still poorly understand the nature of the impacts of the discard banning and there is still a need for detailed long-term seabird and marine mammal population monitoring (Bicknell et al., 2013), in addition to the characterisation of the community structure (Wagner and Boersma, 2011).

3.6. Summary of recommendations

The reduction or elimination of the **bycatch and discards** is one of the core aspects of an EBFM. However, the management procedures should always consider the existing trophic interactions, the relationships between abiotic and biotic ecosystem components and the area-based management.

A discard ban must be accompanied by a suite **of supplementary regulatory measures**, as we have learned from the existing analyses of the consequences of such actions. These measures are fleet dependant, that is, they have to be considered fleet by fleet. For example in Norway the main objective of these measures has been to promote an exploitation pattern where fish below minimum legal size are spared, and where unwanted bycatch can be minimised. This suite has to consider several interconnected measures.

These measures could include a kind of **compensation** for the ex-discards now landed in order to compensate the extra work of handling and processing the unwanted catch that now has to be landed. Another important measure is to **harmonise** the connection between mesh sizes and minimum conservation reference size, considering also the commercial size references, avoiding differences between different areas but equal markets that can confuse consumers. This suite should also ensure that regulations are formulated to **minimise possible incentives to discarding**, for example allocating quotas to cover expected unavoidable bycatches. Finally this suite should also consider the **specific characteristics of some fleets** like small coastal vessels fishing with passive gears, which have limitations in terms of mobility and ability to change fishing ground and hence to avoid some undesired catches.

Development and implementation of exclusive fishing technologies and operational methods could help to achieve a sustainable use of the marine resources. Trade-offs are needed to balance the effects on the different components of the marine ecosystem.

Further ecosystem, whole ecosystem (Plagányi, 2007) or end-to-end (E2E – (Rose et al., 2010)) models should be developed to achieve the **preventative, precautionary and anticipatory planning and management implementation of the EBFM**. Such systems should help to analyse the likely implications of the discard ban in the BoB. Collaboration between different agents working in this area with accessibility to the existing information and databases will be the key to achieving this ambitious goal.

The considerable **reduction in discards** will have direct and indirect **effects on marine predators** that need to be accurately assessed. Therefore, it is necessary to conduct studies to increase our knowledge on the influence of changing discards and natural fish prey availability on predator foraging ecology (in terms of functional responses and searching behaviour) and how the interplay between these two foraging resources influence on fitness, in addition to understanding the wider community responses (Bicknell et al., 2013). In particular, the ICES (2014a) recommended different initiative such as (1) developing an index to score the sensitivity of species to food reduction from discards (and offal), (2) comparing seabird abundance and breeding success before and after the discard ban of the most sensitive species, (3) an integrative meta-analysis of diet studies focusing on the most dependent species to test for species-specific, temporal and regional differences and (4) identifying the most vulnerable seabird colonies.

Specifically in the Bay of Biscay, studies should be undertaken by simultaneously performing studies to estimate population abundance and predator counts attending fishing vessels before and after the discard ban implementation (Louzao & Wilson, pers. comm). On-board fishing vessels, discarding experiments should be performed to obtain discard consumption across

predator communities, seasons and regions. **To understand the role of discards on influencing the ecology and population dynamic of marine predators**, these types of studies might be combined with tracking studies and population monitoring to obtain information on the foraging ecology, reproductive output and survival of seabird populations (Louzao & Wilson, pers. comm.). In the case of marine mammals, an extensive photo-identification effort should be conducted to estimate the probability of calving for reproductive females of marine mammal populations, as well as survival (Tixier et al., 2014).

While an overall ecosystem recovery through a more effective fishing management would be the most desirable management action (Bicknell et al., 2013), ecosystem models can be used to test different scenarios in discard management to identify the most beneficial actions considering predator populations. It is important to consider the different predator population communities, fisheries and fish stock assemblages (Bicknell et al., 2013).

4. General recommendations on the best way to implement the discard plans and the multiannual plans, according to the appropriate scenarios at the regional level

KEY FINDINGS

- The number of stocks with an **unknown stock** status in the BoB is too **high**. Procedures to provide an assessment against the MSY principle should be urgently explored.
- The scientific advisory process should concentrate more on the **mixed and multispecies fisheries**. This recommendation is reinforced by the introduction of the landing obligation.
- Under LO real fishing mortalities will be below target fishing mortalities (FMSY). Harvest control rules based on single-point estimates of fishing mortalities have this effect in a **multispecies context**. We recommend exploring the concepts of multi-stock reference points and Pretty Good Yield or a combination of the two.
- The fishing management procedures should always consider the existing trophic interactions, the relationships between abiotic and biotic ecosystem components and the area-based management.
- A discard ban must be accompanied by a suite of **supplementary** regulatory measures. These measures should harmonize fishing technics, biological reference values, and the demand for fish. They should also ensure that regulations do not disincentive the reduction of discarding and consider the specific characteristics of some fleets.
- **Trade-offs** are needed to balance the effects on the different components of the marine ecosystem.
- Further ecosystem, whole ecosystem or end-to-end models should be developed to achieve the preventative, **precautionary and anticipatory planning and management** implementation of the ecosystem based fisheries management.
- Studies should be undertaken by simultaneously **performing studies** to estimate top predator population abundance and counts attending fishing vessels before and after the discard ban implementation.
- In the case of marine mammals, an **extensive photo-identification** effort should be conducted to estimate the probability of calving for reproductive females of marine mammal populations, as well as survival.
- Ecosystem models can be used **to test** different scenarios in discard management to identify the most beneficial actions considering predator populations. It is important to consider the different predator population communities, fisheries and fish stock assemblages.
- The existing uncertainties in terms of data and dynamics make the application of ecosystem based management a risky exercise. The assessment coming from the ecosystem based management will reflect these uncertainties. However, if we follow a carefully considered **plan**, it will be no more risky than the traditional fishing management.
- The future is not likely to be a simple **extrapolation** of the recent past.
- Fishing fleet's **adaptability** can deal with the undesirable states but can also accommodate or even boost the unexpected opportunities.

A study of attempts of European fisheries trying to recover their stocks (Cardinale et al., 2013) shows that **targeting MSY might** be a good stock recovery method. However, when

recovered, the stocks do not necessarily remain balanced. The study gives several reasons for this conclusion:

- MSY is not a single point, but **an area** where the risk has to be defined. Multispecies and multi-fleet characteristics of the Bay of Biscay make this even more important.
- Implementation of discard plans interferes with obtaining the values close to the MSY. It does not matter if we consider MSY as an area. Fishing **opportunities will be lost**. However, there are no general rules.

There are many reasons to decide on a discard action and the mitigation actions can differ. The study of Sigurðardóttir et al. (2015) has concluded that, given this diversity, the full management system needs to create an **incentive framework** that motivates fishermen to avoid unwanted catches. This framework has to be understood from the economic/financial performance of the fleets but also from their compliance with the rules in place boosting the participation and the overall governance of the industry in the creation of the incentives scheme. It is only in this setting that the discard mitigation methods might be effective.

To consider how to handle these discard mitigation measures we can refer to the study of Catchpole and Gray (2010). The authors have concluded that the fishery crises including incentives, funding, expertise, leadership and enforcement are very important. **Fishery regulators** could take steps to deal with these factors. They could do it by fast responses to the crises, more incentives and funding, greater use of fishermen knowledge and leadership and improved enforcement mechanisms.

In the context of implementation problems, MSY looks like a target and probably a necessary target; however, in itself **MSY is not a plan**. A plan has to involve an ecosystem-based management. There are different levels of the management (see section 4 of this report) and the existing uncertainties in terms of data and dynamics make the application of EBM a risky exercise. However, if we follow a carefully considered plan, the risks will be reduced; it will be no more risky than the traditional FM.

The plan has to be **iterative and adaptive**. The scientific investigation should be linked to the societal debate on management objectives, trade-offs and tools for analysis. No one individual scientist can be fully aware of all activities and links, so it is important to build teams working towards a shared vision, with effective communication between the main players.

The plan must maximise the use of available information rather than accept that insufficient information and the lack of quantitative models will hamper the application of the ecosystem approach. Even the full understanding of the ecosystem does not make the political decision-making easier. Furthermore, the **complexity of governance** should not be an excuse to avoid developing new approaches. The society also has the right to make decisions based on its evolving political processes (Dickey-Collas, 2014).

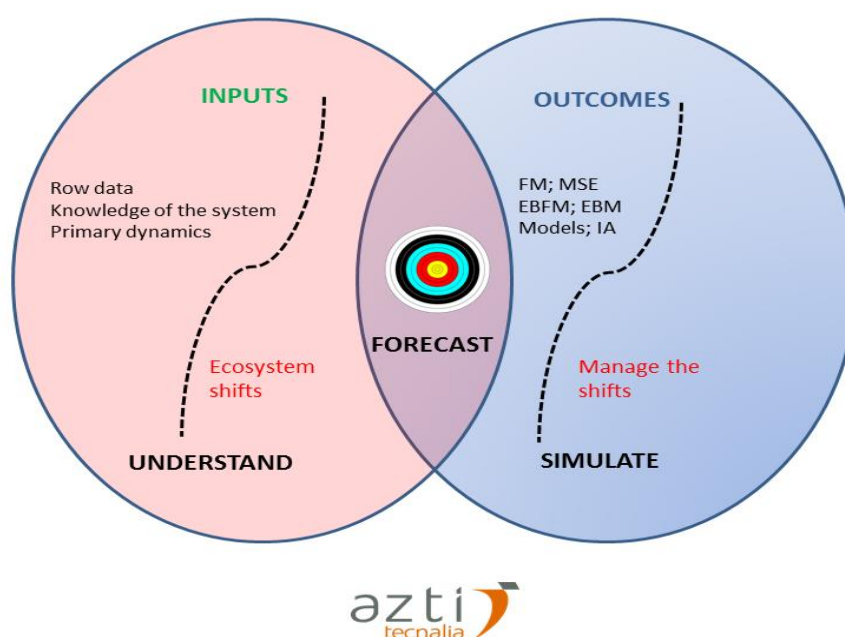
Specific measures can be recommended in terms of the target. The MSY is a CFP objective that can be interpreted; MSY, when presented as a number, is just an **interpretation**. The key factor here is to understand what the MSY seeks for. In the BoB, the main two bodies providing stock assessment advice (ICES and ICCAT) understand well their own interpretation of MSY. However, it does not mean that there is no room for other interpretations.

Part 1 and 2 clearly state that MSY is variable and, furthermore, re-interpretable. The important conclusion is that some flexibility is likely to produce benefits. Flexibilities can be produced without endangering the sustainability. For example, the PGY concept, first mentioned by Alec MacCall (National Marine Fisheries Service, Santa Cruz, California), has

been defined by Hilborn (2011) as a sustainable yield of at least 80% of the maximum sustainable yield. PGY theory acknowledges the fact that **MSY is just an average**, and as it is sustainable and “pretty” optimal, other uses and/or societal pillars can be considered without invalidating the MSY concept. This **flexibility** is important in the **management**. It also avoids the criticism that MSY ignores the multispecies, multi-fleet and ecosystem components of the fisheries (Larkin, 1977; Prellezo and Curtin, 2015). Furthermore, it provides room for trading-off between the economic and social sustainability pillars.

This approach is also in accord with the iterative and adaptive characteristics that any plan would need. Exacerbated by the recent economic crisis, the general management policy and, in particular, *EBFM*, have become “**predict and prescribe**” strategies. This is probably a result of our limited understanding of the ecosystems. However, predictions have to be based on what we know and it is important not to base all our expectation on what could be called a giant with feet of clay. Furthermore, the future is not likely to be a simple extrapolation of the recent past.

Figure 13. Forecast scheme. Understanding the basics and simulating.



Source: AZTI

Forecasting (Figure) requires a **complex balance**; it has to be robust enough to acquire new basic data, but also consider the regime shifts. The modelling or simulation on the basis of insufficient data can cause undesired results. In Section 2 of this report, we introduced the Management Strategy Evaluation (MSE) as a way of designing feedback control systems. Adaptation allows reducing uncertainty by monitoring over time. However, the adaptive management faces exactly the same challenge of finding the right balance between gaining new data to improve management in the long-term and achieving the best short-term outcome based on the current knowledge. In both cases, MSE and adaptive management, monitoring the response of populations to management and the environment are of primary importance (INPUTS of Figure). In Europe, the Marine Strategy Framework Directive (MSFD) places a legal requirement to consider the impact of fishing on population demography, genetics and Good Environmental Status (GES). MSE is an adequate approach integrating these factors, **not focusing on the prediction power but on the scenarios** that represent possible, plausible, internally consistent, but not necessarily probable, developments (Carter et al., 1994).

Science should focus on balancing the two sides of forecasting (Figure). However, this should include the predictions based on the best available knowledge and avoidance of prescriptions. The risk of each possible outcome has to be evaluated by the society using their political processes.

Flexibility is important, as highlighted by Schindler and Hilborn (2015): “The ability to adapt to ecosystem changes revealed by monitoring and assessment is likely to be a far more powerful strategy than assuming that what has worked in the past will work in the future”. Adaptability can deal with the undesirable states but can also accommodate or even boost the unexpected opportunities.

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DIRECTORATE-GENERAL FOR INTERNAL POLICIES
POLICY DEPARTMENT B: STRUCTURAL AND COHESION POLICIES

FISHERIES

The discard ban and its impact on the MSY objective - The Baltic Sea

STUDY

Abstract

Achieving maximum sustainable yield (MSY) exploitation is one of the reformed CFP's central aims. We explore which factors would need to be considered to achieve the MSY in the Baltic Sea, namely the consideration of interactions between fish stocks (including the definition of new targets), of all anthropogenic mortalities (specifically recreational fishing), and of issues around the implementation of management measures. One of the supporting measures, the Landing Obligation, has likely little if any adverse effects to the Baltic ecosystem.

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LIST OF ABBREVIATIONS

C	Carbon
CCTV	Closed-circuit Television
CFP	Common Fisheries Policy of the EU
CPUE	Catch Per Unit of Effort
DDT	Dichlorodiphenyltrichloroethane
EP	European Parliament
EU	European Union
FDF	Fully Documented Fishery
Fmsy	Fishing mortality that produces the maximum sustainable yield
HELCOM	Baltic Marine Environment Protection Commission – Helsinki Commission
ICES	International Council for the Exploration of the Sea
ITQ	Individual Transferable Quota
MCRS	Minimum Conservation Reference Size
MCS	Monitoring, Control and Surveillance
MLS	Minimum Landings Size
MSY	Maximum Sustainable Yield
N	Nitrogen
NGO	Non-Governmental Organization
P	Phosphorus
PCB	Polychlorinated Biphenyls
POP	Persistent Organic Pollutant
PECH	European Parliament’s Committee for Fisheries
PSPC	Potential Smolt Production Capacity
QR code	Quick Response Code
RBM	Results-Based Management
REM	Remote Electronic Monitoring
STECF	Scientific, Technical and Economic Committee for Fisheries
TAC	Total Allowable Catch
TAL	Total Allowable Landings
ToR	Terms of References

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EXECUTIVE SUMMARY

Achieving the **maximum sustainable yield (MSY)** exploitation by 2020 at the latest is one of the key elements of the **reformed EU Common Fisheries Policy (CFP)**. The MSY is **currently defined** in a **single species** (or stock) context, but MSY targets will likely change if considered in a **multi-species** or even an **ecosystem context**. The available results from a **multispecies system** produce **not one single biological optimal solution** for a maximum yield, **but many**. In the Baltic, policy makers have to **choose between a cod dominated or a herring and sprat dominated system**, or anything between these extremes. It is difficult to reach an agreement among Baltic Member States on the targets, because there are diverging interests. We suggest to **search for factors other than yield**, such a quota stability, to facilitate the decision making process, and provide an example where the stability in yield for one stock is the major objective (section 1).

Moreover, the MSY estimate is affected by different sources of **uncertainty**, and the successful implementation of an MSY approach will be substantially influenced by **other management considerations: additional anthropogenic mortality** on exploited stocks (**recreational fisheries** – section 2), **impact of other human activities on the ecological status** of the Baltic Sea environment (section 3), **effects of the Landing Obligation on the ecosystem** (section 4), and the **implementation error** of the reformed CFP (section 5).

(1) The **incorporation of the total anthropogenic mortality** needs to involve **recreational fisheries** that have a high impact on marine fish stocks worldwide and in the Baltic Sea due to significant removals (**low catches per recreational fisher but millions of fishing days**). However, many national recreational fisheries surveys are still incomplete or lacking completely making it difficult to understand the relative pressures and impacts of all fisheries in a region. The availability of marine recreational fishery data is crucial to design and evaluate effective recreational management measures. Due to the **heterogeneity of recreational fisheries**, management measures must be tailored to the individual Member States and their fisheries. Including recreational mortality into assessment models inevitably challenges the management regarding the **allocation of resources between the commercial and the recreational sector**. To increase ecosystem services and assess the potential for growth in both sectors, development of a **co-management framework** that balances environmental, economic, and social effects of recreational and commercial fishing will be required.

(2) Stock development not only depends on fisheries management, but also on the **ecological status of marine ecosystems**. The **Baltic Sea** is the **world's largest brackish-water ecosystem** and suffers from **numerous pressures**, involving eutrophication, large zones at the seafloor with very low or without oxygen, toxic pollutants, coastal degradation, expansion of non-indigenous species, and climate change. Consequently, future management needs to be **flexible to include these pressures**, with management targets continuously adjusted. The present disconnect and fragmentation of institutional arrangements and management bodies needs to be overcome.

(3) The **EU Landing Obligation** aims at **reducing discards of quota species**. In the Baltic Sea, discards of salmon are very small, discards of herring and sprat are negligible. Only **cod, plaice** and some flatfish species not regulated by catch limits **cause relevant amounts of discards** which are, however, **minor** (around 2%) **when compared to the total landings** from the Baltic Sea. Non-quota regulated and bycatch species and fish offal can be still discarded after the introduction of a Landing Obligation. Consequently, **avian scavengers** (mainly herring gull *Larus argentatus*) are **unlikely to suffer** from adverse large-scale effects

of the Landing Obligation, but local effects in certain areas cannot be excluded. The **consequences on benthic scavengers** are largely **unclear**.

(4) Fisheries management has often failed to achieve the intended level of resource exploitation due to **implementation error** (this is largely the **failure to control exploitation** by all kinds of measures adopted to monitor, control and surveil the use of fisheries resources). For instance, under landings quotas the fishing mortality rates are not limited, causing an implementation error. In contrast, under catch quotas (**landings plus discards**) this source of implementation error is avoided, but only if all catches of quota species are accounted for. Full catch accountability can be achieved by observers or remote electronic monitoring including closed circuit television (CCTV), i.e. **fully documented fishery (FDF)**. A fisheries management could be improved by a **quid-pro-quo** or **tiered approach**, when groups of fishers (or Member States) deploying FDF are entitled to catch their full quota shares, whereas groups of fishers (or Member States) without FDF would be assumed to discard; these assumed discards would be subtracted from their quota share. Some of the past implementation error may have been caused because the **complex top-down control** and **lack of trust** have undermined fishers' potential intrinsic **motivation to fish sustainably**. Compliance is not necessarily a function of the economical pros and cons of rule violation: compliance may be higher or lower, depending on intrinsic motivations; monetary incentives may undermine such motivations. An **increased level of self-decision** may lead to more buy-in to sustainable fishing practices and voluntary compliance to catch limits and the Landing Obligation. Behavioural science showed that people in small and self-selected groups are inherently more likely to behave "pro social". Some key recommendations are given for changes, e.g. in institutional settings, that may increase **voluntary compliance** and sustainable fishing practices. However, transition to a system allowing for more freedom from top-down regulation, with more self-governance, may be difficult and may take many years but is expected to ultimately pay off.

INTRODUCTION

KEY FINDINGS

- Achieving the **maximum sustainable yield (MSY) exploitation** by 2020 at the latest is one of the **key elements** of the reformed **EU Common Fisheries Policy (CFP)**
- The MSY is currently defined in a **single species context**, but MSY targets will likely change if considered in a **multi-species** or even an **ecosystem context**.
- Measures implemented to achieve the MSY, such as the **Landing Obligation**, might have **adverse effects on other non-target ecosystem elements**.
- Other management considerations with important effects on the successful implementation of an MSY approach include the **incorporation of total anthropogenic mortality** on commercially exploited stocks and the **minimisation of the implementation error**.
- **The Baltic Sea** has a comparatively **simple-structured ecosystem** and **fishing fleet** and is thus considered a **good model region for exploring the impact of management measures** in EU waters. It is also a region where considerable progress has been made on multispecies modelling, where few scavenger populations benefit from discarding, and where recreational fishing has been demonstrated to have an important impact on the harvest from marine stocks.

One of the most important aims of the reformed EU CFP is achieving the MSY exploitation of all managed European fish stocks no later than 2020 (Regulation (EU) No 1380/2013). Other aims of the reform include an ecosystem-based approach to fisheries management, long-term environmental sustainability of fishing and aquaculture operations, and the elimination of discards. These aims and the approaches to achieve them are strongly interlinked.

Despite the apparent clarity of the MSY objective, the basic regulation leaves room for interpretation of the term “maximum sustainable yield”. At present, MSY targets are derived in a single species context, while it is widely recognised that these could be very different if interactions between different fish populations or other elements of the marine environment are considered. Moreover, single species’ MSY targets cannot be reached for all commercially exploited fish stocks within one region simultaneously.

Part of the problem is that multi-species modelling has only recently started to be used for fisheries management. In many cases the data required to arrive at results which could be used for fisheries management are still inadequate. It is also clear that other management considerations will have an influence on the successful implementation of an MSY approach, namely the consideration of all human impacts on fish stocks, and the implementation error for the new rules (implementation error is the failure to control exploitation by all kinds of measures adopted to monitor, control and surveil the use of fisheries resources). Some of the measures implemented to achieve the MSY might have adverse effects to other ecosystem elements – for example, eliminating discards are expected to promote the recovery of overfished stocks, but might at the same time lead to a reduction of the population of avian or benthic scavengers.

Terms of Reference

The European Parliament's Committee for Fisheries (PECH) therefore commissioned a number of regional case studies on the topic, with very similar terms of reference (ToR) among the regions. For the present study considering the Baltic Sea, these ToRs are:

- The in-depth study will focus on EU waters of the Baltic Sea, a specific case-study, to provide the relevant knowledge to implement the discard plans and multiannual plans, managing the harvested stocks to levels that can produce the MSY, taking into account the status of the ecosystem.
- The study will be based on the best suitable existing data and information obtained from the fishing fleets operating in the marine area defined for the case-study and from the results of the scientific modelling work conducted in the region.
- The study will develop a summary report of the state for the art scientific knowledge on the above objectives, provide different practical options for the management, and describe and analyse the following topics:
 1. A summary of the current state of MSY modelling in the region, including specific outcomes and main conclusions. The summary will identify and analyse objectives, stocks and fleets, interactions, uncertainties - according to the indicators used. It will also produce an assessment of those elements not included (such as removals by non-commercial fleets) and their likely influence on reaching the objectives of the CFP in the short and medium term.
 2. A bio-economic analysis based on a case-study in the region on the likely consequences of the Landing Obligation regarding the objectives of the CFP, specially the MSY. For this purpose, different scenarios and/or practical options should be identified and assessed, considering risks, uncertainties and the main interactions.
 3. An assessment of the main impacts that Landing Obligation in the context of the MSY may have on the ecosystem of the region, identifying and analysing the related uncertainties.
 4. An analysis of the approaches on how to implement the new rules effectively and in line with the objectives of the reformed CFP, including an assessment of the implementation error, and a provision of strategies to minimise the implementation error by applying findings from behavioural economics.
 5. Based on these analyses, recommendations will be made to the European Parliament providing the knowledge on the best way to implement the discards plans and multiannual plans according to the different scenarios at the regional level.

Structure of the report

After discussion with the client, we adapted the structure of the work to account for the peculiarities of the Baltic Sea region. The ToRs are still addressed but the report structure does not match the structure of the ToRs. Extensive modelling was not considered imperative within this study because most of the multispecies modelling has been conducted recently (during 2010-2012). The results of this recent work are sufficient to illustrate the challenges for the implementation in a fisheries management. They would have to be updated again before multispecies considerations are actually implemented in a management plan, but at present such an update is impossible as basic data from an analytical stock assessment are missing for one of the key fish stocks, i.e. the eastern Baltic cod.

Ecosystem modelling (regarding the effects of the LO) was also considered unnecessary as the amount of the biomass removed from the system after a full implementation of the Landing Obligation – and thus the effect on scavengers – is found to be comparatively small. Instead, we put more emphasis on the effect of additional removals from human activities other than commercial fishing, and on the minimisation of the implementation error. Both factors have consequences for achieving an MSY exploitation. Unfortunately, these consequences are largely underestimated and inappropriately accounted for in fisheries management.

Following this introduction, the report is structured in four major sections:

In **Section 1**, we present the results of the **multispecies modelling work** conducted by the Scientific, Technical and Economic Committee for Fisheries (STECF) and the International Council for the Exploration of the Sea (ICES) expert groups in 2010 through 2012 during the evaluation of the Baltic cod management plan. At that time, various options for implementation were outlined, ranging from a herring-sprat dominated to a cod dominated ecosystem. The management, however, was neither able to decide on one of the options nor requested alternatives, but instead continued with a single species management. We outline what went wrong in the process and discuss alternative solutions, e.g. balancing objectives other than just yield, such as the stability of catches.

Sections 2 and 3 address the impact of **other human activities** on commercial fish stocks, especially **recreational fishing**. We know from data collections since 2004 that anglers can remove a large fraction of some Baltic fish stocks, most importantly western Baltic cod and sea trout. We outline why recreational fisher's catches should be included in the assessment, why anglers are important for any MSY consideration, why they are important for the economy of coastal regions, and which management approaches for angling appear to work.

The **impact of policy changes on the Baltic Sea environment** are outlined qualitatively in **Section 4**. This mainly addresses the changes expected after a full introduction of the CFP reform and considers the effect of reduced discards, e.g. on scavenging sea birds.

The final **Section 5** discusses issues around the **implementation of the rules**. We are interested in approaches to ensure the MSY objectives of the CFP reform can be fully met. The minimization of implementation errors is an important aspect to ensure that catch limits maintain populations of harvested stocks at levels compatible with MSY. Implementation error has contributed to a large extent to past failures of fisheries management.

Therefore, in addition to quantitative analyses to inform how catch limits need to be set in discard plans and multiannual plans, an analysis of factors underlying implementation error is necessary. One obvious factor is enforcement of the discard ban and the catch limits. Under landings quotas, it was relatively easy to monitor the landings in the ports, but landings quotas did not limit fishing mortality and this was a large contribution to implementation error. Under catch quotas, it is not clear how the Member States will monitor the catches and enforce the discard ban. Fully Documented Fisheries (FDF) might be one approach; another is a tiered approach, where the higher the uncertainty of the documented catches, the more conservative the catch limits will be. Another component of implementation error is the level of adherence of the individual fishers to the rules and regulations. Findings from the behavioural sciences (e.g. behavioural economics) provide insights into how the institutional settings, framing, incentive-structure (non-economic as well as economic incentives), and choice architecture influence fisher behaviour rationally and irrationally. We conducted an initial analysis into these influences, accompanied by suggestions for mitigation of negative influences.

Special features of the Baltic Sea

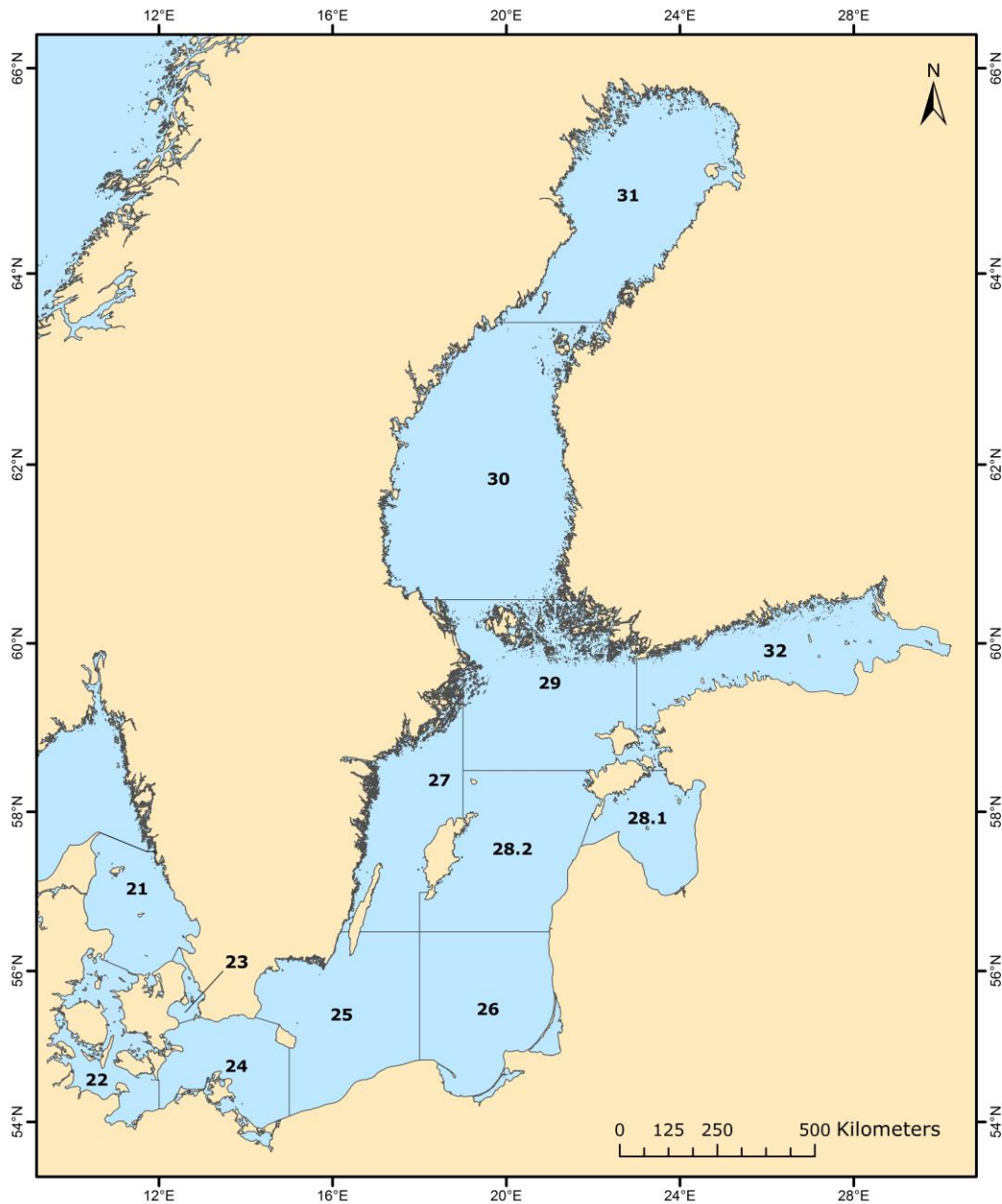
The Baltic Sea (Map) is different from most other EU waters. It is one of the largest brackish water areas in the world. While the terrestrial (freshwater) runoff into the Baltic Sea is significant, saline water only enters from the North Sea. The Baltic Sea is eutrophic (nutrient-rich), and in the deeper basins large zones with low or without oxygen (hypoxic or anoxic) occur frequently. Bottom water in these basins usually has a much higher salinity than the surface water. The density stratification is strong and vertical mixing only affects the bottom water in the shallower western Baltic Sea (and surface water bodies elsewhere). Thus, the oxygen supply of the bottom water in the deeper basins in the east only comes with lateral inflows of saline water (of higher density) from the North Sea (Feistel *et al.*, 2008).

Both salinity and oxygen content severely influence the distribution and development of marine fish species in the Baltic Sea. There are a few marine species and a few freshwater species, both more tolerant against the reduced and partly variable salinities. In the Baltic Sea, environmental factors have a much greater impact on the status of commercially exploited fish stocks than in most other European seas. Due to the importance of the environmental conditions for the system, not only the fauna of the Baltic Sea is simpler than in most other regions, but also the interactions between those species are simpler than e.g. in the adjacent North Sea (Hammer *et al.*, 2008). Those simple interactions facilitated extensive ecosystem modelling, to determine the mechanisms observed after environmental regime shifts. Furthermore, multispecies modelling on commercially exploited fish stocks was conducted in the eastern Baltic Sea, where an analysis of only three species (cod, herring and sprat) was sufficient to already map most of the interactions.

Likewise, the structure of the fisheries is relatively simple. There are only fisheries of nine nations exploiting the marine living resources of the Baltic Sea (eight EU Member States and Russia). Commercial fisheries can be broadly separated into active and passive fleets. They all exploit adult fish and are relatively similar across nations. Bycatches of target species' juveniles and of protected fish species rarely occur. Moreover, compliance appears to be reasonable, at least in most nations and in recent years. The Baltic Sea was therefore the EU region where the discard ban was implemented first: for sprat, herring, cod and salmon in January 2015 and for plaice as of 2017.

However, the ecosystem modelling in the Baltic Sea is being suspended because since 2014 there is no analytical stock assessment of the largest demersal commercial fish stock, the eastern Baltic cod (i.e., there is no information on spawning-stock biomass and fishing mortality). The traditional stock assessment cannot be performed because of data issues (e.g. severe uncertainty in age and growth data) and complex environmental influences (involving e.g. hypoxia) (Eero *et al.* 2015). The problems cannot be readily solved and may continue for the next years. Consequently, we face the unusual situation that the status of the regions' largest demersal stock cannot be fully assessed and are confronted with the view that the Baltic Sea and its ecological interactions may be more complex than previously thought.

Map 1: The Baltic Sea and adjacent waters with limits of ICES Sub-Divisions (SD) indicated.



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Sources: ArcView and ICES.

1. MULTISPECIES CONSIDERATIONS AND MANAGEMENT

KEY FINDINGS

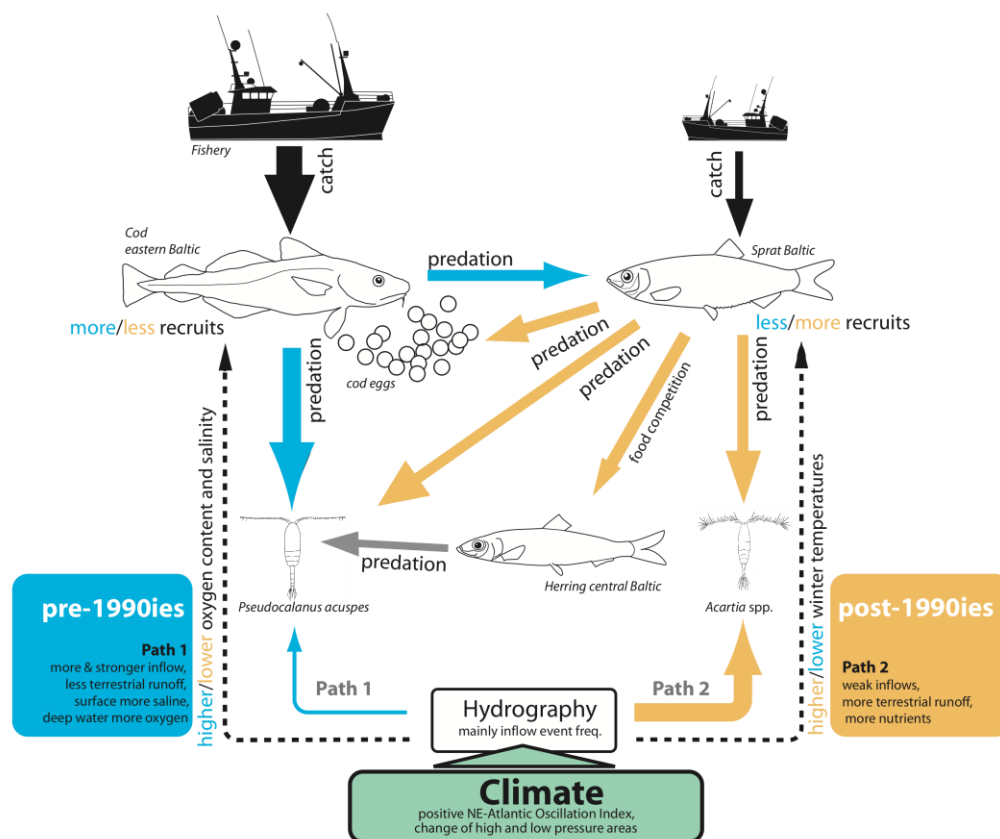
- The MSY is currently defined in a **single species context**, but MSY targets will likely change if considered in a **multi-species** or even an **ecosystem context**.
- **Multispecies modelling** for the eastern Baltic Sea demonstrated that the **combined yield for cod, herring and sprat could be higher than at present, but** at the same time **fishing mortalities** consistent with the MSY would be **much higher** and the **risk for the spawning stock biomass** to fall below limits **would increase**.
- A **societal decision on the targets for optimisation** would be required (e.g. for highest yield in biomass, or protein for human consumption, or profit for the fishery; or whether the system should be cod-dominated, sprat dominated or something in between). There is **no biologically optimal solution** to this problem.
- Policy makers felt unable to make this decision and **decided not to start implementing a multispecies management**, although this could be seen as a first step towards an ecosystem approach to fisheries management, which is a declared element of the EU fisheries policy.
- We consider it very difficult to reach an agreement among Baltic Member States on the targets, because they have divergent interests. We suggest to **search for factors other than yield** to facilitate the decision making process, **such as stability in yield**. We explore one example where the stability of quota for cod is the major objective.
- It appears unlikely that the **effect of the Landing Obligation** will have the potential to measurably alter those parts of the food web in the eastern Baltic Sea which are considered in multispecies modelling.

1.1. Multispecies modelling of the Baltic Sea ecosystem

At present, for most fish stocks in EU waters targets and limits required for an MSY approach management are derived in a single species context (i.e. for a single fish stock). However, different fish stocks in the same region often interact with each other, e.g. they feed on each other or compete for the same prey or spawning grounds. It is widely accepted that MSY targets or limit reference points would be very different in a multispecies context than they are in a single species context, and that single species MSY targets cannot be achieved for all commercially exploited species in one region at the same time.

A good illustration is the situation in the eastern Baltic Sea, where cod feeds on small pelagics (herring and sprat), which compete for the same food source (zooplankton). Under certain conditions sprat, in turn, can regulate the cod stock productivity when adult sprat feed on cod eggs. This leads to periods with either high cod biomass and low sprat biomass, or vice versa (e.g. Hammer *et al.*, 2008). Environmental conditions such as temperature, salinity or oxygen content in the bottom waters, play a much more important role in the Baltic Sea than in other EU waters. Fundamental changes in these conditions, so called regime shifts, might trigger the transformation into another ecosystem state (Eero *et al.*, 2008; MacKenzie *et al.*, 2007; Köster *et al.*, 2003; Köster and Möllmann, 2000; Figure 1).

Figure 24: Schematic presentation of the interrelation between climate, environmental factors and the development of commercially exploited fish stocks in the eastern Baltic Sea.



Source: from Hammer *et al.*, 2008, after an idea of Möllmann, modified.

To describe the linkages between different stocks, **multispecies modelling** was developed already in the late 1970s (reviewed in Pope 1991) and gained importance at the beginning of this century (e.g. Vinter 2001). Results of the multispecies modelling were on occasion used to **detect changes in natural mortality (M)**, and they still inform the stock assessments in this respect. However, until 2012 fisheries science did not try to deliver management advice including multispecies considerations. This was done by a joint working group of the International Council for the Exploration of the Sea (ICES) and the International Council for the Exploration of the Sea (STECF) (ICES 2012a; STECF 2012), to address a request of the European Commission to propose a **multispecies management plan for the Baltic Sea** superseding the Baltic cod management plan of 2007 (EC Reg. 1098/2007). The extensive modelling work revealed, in short (ICES 2012b):

- fishing mortalities derived from multispecies modelling consistent with the MSY approach (Fmsy: fishing mortality that produces the maximum sustainable yield) were, for most stocks, remarkably higher than single species' Fmsys; (for cod: single species (ss) Fmsy=0.3 / multi species (ms) Fmsy=0.60-0.65, herring: ss Fmsy=0.16 / ms Fmsy=0.26; sprat ss Fmsy=0.35 / ms Fmsy=0.46);
- combined yield (MSY) when fishing at multispecies' Fmsys was higher than the estimated yield derived from single species assessments; it was much higher for herring and not significantly higher for cod;
- the risk for stocks fished at the higher multispecies Fmsys to fall below the biomass limit reference point increased moderately;

- and most importantly: It appeared possible to maximize the combined yield for either highest cod yield or highest herring and sprat yield, which also means that the system could be exploited in a way that it would either become cod dominated (high cod biomass and yield, low pelagics biomass and yield) or pelagics dominated, or anything between these extremes.

The work also demonstrated some significant limitations of the modelling work: It was found that information on **connections in the food web**, mainly derived from stomach content analysis already conducted in the 1980ies ("who has eaten what") was old and probably outdated, as biomasses of the stocks concerned and, more generally, the environmental conditions in the Baltic Sea had changed significantly since the 1980s. Further, the analysis assumed no spatial segregation of the three stocks, or at least a significant overlap of the distribution area. More recent data has, however, demonstrated that the eastern Baltic cod stock is mostly concentrated in the Bornholm Sea (SD 25 and 26, Map), while the center of gravity of distribution of sprat is much further to the north, south of the Archipelago (SD 29, Map). It was therefore strongly recommended to update food web data and to make the models more spatially explicit, which would also require additional distribution data.

A decision would now be required on the **management targets**: There was **not one** single biological optimal solution for a maximum yield from a multispecies system, **but many** of them. Managers could wish for an maximization of the cod or the pelagics (sprat) yield, or for various MSY targets, such as maximum harvest of biomass, protein (overall or for human consumption, as most of the sprat yield of some nation's fisheries is used for industrial purposes), of landings value, fisher's income or employment. The final decision to optimise towards one of these potential targets could not be taken by scientists but required a **societal agreement**.

1.2. Incorporation of multispecies aspects in the management

When the results of the modelling were presented to policy makers in 2012, they found them bluntly "useless" and questioned the whole approach. In fact, management decided to stick to single species assessment results which gave slightly lower yields but with lower fishing mortalities and a lower risk for spawning-stock biomass – a decision supported by science for the time being and which is still the basis of the management of commercially exploited fish stocks in the Baltic. Single species considerations also form the basis of the new multi-annual management for the Baltic Sea, the first plan to be developed after the CFP reform was implemented. In conclusion, there is **no progress**, neither at present nor in the foreseeable future, with the implementation of multispecies and thus **ecosystem considerations into fisheries management**.

In its 2012 advice, ICES stipulated that "the present section may serve as a starting point for a dialogue between ICES and managers to foster the development of a multispecies management system for the Baltic. This text uses implicit management objectives and risk tolerance that need to be validated by managers. If managers decide to adopt a multispecies management approach, a transition period from the present management will be required." And further: "The societal choice between [the options provided] must be based on social and economic considerations and informed by social and economic impact assessments."

Subsequent research in the Baltic Sea within the frame of the MYFISH project¹⁹ included considerations on multi-species modelling but also climate changes and their potential ecological, economic and social consequences (e.g. Möllmann et al. 2013, Voss et al. 2014a,b, Bleckner et al. 2015), although this did not influence political decision making.

¹⁹ <http://www.myfishproject.eu/project-myfish/myfish-overview>; <http://myfishproject.eu/media-centre-2/news>

It might be useful to explore the reasons why policy makers have decided not to start this dialogue. We suggest that the preferences for management targets are so diverging among the different Member States involved in the use of this resource (and possibly even more among the wider group of stakeholders), that agreeing on targets is just not feasible. Very simplified, the **"southern" Baltic** fisheries have a higher interest in cod and thus would prefer a cod-dominated ecosystem (with higher cod biomass and yield but lower pelagics yield). The **"northern" Baltic** fisheries have a higher share on the sprat and herring catches and thus a greater interest in higher fishing opportunities from the small pelagic stocks. From a biological point of view, one of those options would be as good as the other or any option in between, and all of them could be sustainable and in line with an MSY approach.

An agreement or at least the start of a discussion on potential targets might be possible if factors other than yield are considered. An in-depth analysis of potential drivers (for fisher's behaviour) would be required to identify such factors. One potential target could be the **stability of quotas**: this is an element which is very desirable for the **cod** fishery, which is mostly conducted by smaller vessels with limited flexibility to move to other fishing grounds if the quota for cod in the Baltic is insufficient. The **sprat** fishery, in contrast, consists to a large extent of larger vessels, which only fish in the Baltic for part of the year when the fish is aggregated. These vessels usually also fish for other pelagic stocks in the North Sea (e.g. sprat, sandeel, Norway pout) and could probably better cope with larger inter-annual fluctuations of the quota.

We therefore modelled a situation with the following assumptions:

- the **cod** yield (TAC) is fixed at 70 000 t for 10 years (after the recovery of the stock to more than 150 000 t total stock biomass), which is about **45% higher** than the mean landings and **21% higher** than the TACs over the last 10 years;
- **sprat and herring** TACs are allowed to fluctuate, and we expect that these fluctuations are more pronounced than under the present management regime. Pelagic fisheries would have access to the "surplus" which would be left after a cod stock of the size required to produce 70 000 t yield is satisfied;
- recruitment of the cod stock varied randomly by 20% around the mean observed recruitment.

The results of this exercise show that, under these assumptions, the **biomass of the cod** stock would increase by more than 25% in most cases (to more than 200 000 t in 89 out of 100 model runs). This would mean that a larger cod stock would feed on more pelagic fish and thus reduce the fishing opportunities for the pelagic fleet. The risk for the cod stock biomass to fall below the initial biomass is low (3 out of 100 model runs), the cod stock would likely be underutilised at the end of the 10 year period. Therefore, such an approach would be acceptable for the cod fishers but still not be optimal for the pelagic fishers.

The results suggest that further iterations are needed where our modelling approach could be refined with higher cod yields or lower starting biomasses. It should also be noted that a random variation of **20%** for **the recruitment** in our example is rather low and would probably become much higher if the **environmental conditions** change drastically, as they have regularly done in the past. However, the work seems to be sufficient to illustrate the potential of the incorporation of additional factors such as the stability of quotas in the discussion on MSY targets.

1.3. Update of the multispecies modelling

The results of the multispecies modelling work are now 4 years old, and some of the input data was considered outdated already when the work was conducted (see above). If to be used for the development of a management plan, these **data and the modelling** would need to be updated. Stomach content analyses are underway to update the food web data. However, ICES is currently not able to provide a single species assessment for the eastern Baltic cod stock, which is a prerequisite for the multispecies work. We expect that the current assessment problems can be solved in the next years. This gives time to explore the principles and targets of a future multispecies management, if deemed useful by policy makers.

1.4. Considerations on the impact of the discard ban on multispecies MSYs

It appears unlikely that the effect of the Landing Obligation will have the potential to measurably alter the food web in the eastern Baltic Sea, because the additional removal of fish forced by the Landing Obligation is just too small (see section 4). Discards of **herring** and **sprat** were negligible even before the discard ban, and **cod** discards will likely be reduced in the future (if the rules are properly implemented). This might reduce the fishing mortality on young cod and thus increase the predation on small sprat and herring. Given the uncertainty in the input data (see above) and the large impact of variable environmental conditions on the development of cod, herring and sprat in the eastern Baltic Sea, the effects of this potentially increased **mortality** of young sprat and herring can probably not be separated from other factors.

2. IMPACTS OF OTHER HUMAN ACTIVITIES ON COMMERCIAL FISH STOCKS: RECREATIONAL FISHERIES

KEY FINDINGS

- **Recreational fisheries have a high impact on marine fish stocks** worldwide and in the Baltic Sea. Recent surveys show that for some species – **namely western Baltic cod, salmon and sea trout** – recreational fishery catches can have a significant share of the total landings.
- **If recreational fisheries data are excluded from assessments**, it is not possible to accurately determine all direct human impacts on fish stocks and **this jeopardizes our ability to achieve the maximum sustainable yield (MSY)**.
- Although large components of recreational catches are kept, substantial proportions **are released alive**, and **in the case of cod most of them survive** indicating that recreational fisheries releases are reconcilable with the new Common Fisheries Policy (CFP). No estimates of release survival are available for Baltic salmon and sea trout.
- Many **national recreational fisheries surveys are still incomplete or lacking completely** making it difficult to understand the relative pressures and impacts of all fisheries in a region. However, the availability of marine recreational fishery data is **crucial to design and evaluate effective recreational management measures**.
- Including recreational mortality into assessment models inevitably challenges management regarding the **allocation of resources between the commercial and the recreational sector**.
- **Management measures that imply very large annual reductions** of fishing opportunities to achieve MSY and include the recreational sector **should make sure not to jeopardize the social and economic sustainability of the sector** at large.
- Recreational **management measures must be tailored to the individual Member States** and their fisheries.
- Developing a **co-management framework that balances** environmental, economic, and social effects of **recreational and commercial fishing** is the next challenge. This should increase ecosystem services and assess the potential for growth in both sectors.

In the past, the impact of recreational fisheries (particular angling) on marine fish stocks and ecosystems has been frequently neglected, but in recent years it has become increasingly recognized by fishery managers (e.g. Post *et al.*, 2002; Coleman *et al.*, 2004; Cooke and Cowx, 2004, 2006; Lewin *et al.*, 2006). The marine recreational fishing sector also has high **economic value and social benefits**. Cisneros-Montemayor and Sumaila (2010) estimated that in 2003, 58 million recreational fishers were fishing in the sea worldwide, generating a total of 39.7 billion USD in expenditures and supporting almost 1 million jobs. Another study by Cooke and Cowx (2004) estimated a global recreational fishing participation **rate of 11.5%** (all ecosystems) resulting in a global recreational catch of 47 billion fish and harvest of 17 billion fish (equal to 10.9 million tons). Thus, recreational fisheries account for roughly 12% of the total global fish harvest (FAO, 2014). Ignoring this contribution of recreational fishing on total fishing mortality could have consequences for economically and ecologically important fish stocks, as it locally could contribute to overfishing (Cooke and Cowx, 2004; 2006; Lewin *et al.*, 2006). Although marine recreational fishing is a popular leisure activity throughout Europe, with at least **8-10 million participants** and total expenditures valued at 8-10 billion Euro (Pawson *et al.*, 2008), relatively little effort has been undertaken in the past to investigate its ecological, economic and social impacts. Only recently, research efforts in marine recreational

fisheries across Europe have started to increase (e.g. Pawson *et al.*, 2008; Sparrevohn and Storr-Paulsen, 2012; Strehlow *et al.*, 2012; Ferter *et al.*, 2013; ICES, 2015a). If recreational fisheries **data are excluded from assessments**, it is not possible to accurately determine all the human impacts on stocks, and this jeopardizes our ability to achieve MSY.

Marine recreational fishing in the Baltic Sea is a popular leisure activity with approximately 1 million fishers (Strehlow *et al.*, 2012; Sparrevohn and Storr-Paulsen, 2012; Sveriges Officiella Statistik, 2013). Marine recreational fishing also provides important social and economic benefits to society. Recreational fishing is carried out from two different platforms: the shore (**land-based**) and boats (**sea-based**). In Germany for example, fishing from the shore (surf angling and wading) and sea-based fishing methods (private boat and charter boat angling) are equally popular with the fishing effort almost evenly split in the Baltic Sea (Strehlow *et al.*, 2012). **The marketing of catches from recreational fisheries is prohibited in Europe.**

Recreational fisheries may operate in similar ways to small-scale commercial fisheries involving a large number of small vessels (<10 m length over all) and thus should be considered as a component of small-scale fisheries. Recreational fishers may operate in similar areas and target similar species assemblages as **small-scale commercial fisheries**. This is particularly the case in the western Baltic Sea. Next to the most popular used fishing method in the Baltic Sea such as rod-and-line, recreational fishers use nets, pots and go spearfishing. The main species targeted by fishers in the Baltic Sea are cod, herring, mackerel, flounder, plaice, dab, sea trout and salmon. Recreational fishing licenses are obligatory in only few Member States. Accordingly, the total number of recreational fishers and thus catches is unknown and needs to be estimated by recreational fishing surveys. There are **three main notable challenges** associated with recreational fisheries data collection: **(1)** there is no central **registration** of recreational fishers, **(2)** recreational catches are not documented (no sales slips due to prohibition of marketing catches), and **(3)** recreational fishers fish in remote and hard to access areas. As a result, recreational fishing surveys are complex and difficult to conduct, often requiring a number of different surveys to **collect data** on effort (e.g. total number of recreational fishing trips), catch per unit effort (e.g. catch per fishing day), **biological composition** of the catch (e.g. size or age composition if catch at **size or age** is needed for an assessment), post-release mortality (to quantify the proportion of released fish dying) and **economic value** (to assess the contribution of the sectors) (ICES, 2015a).

2.1. Why is it important to involve recreational fisheries in management?

Although the average catch rate may be low in the recreational fishery, the **total catch** numbers may be very high due to the sheer number of recreational fishers. In Germany for example, the average harvest of charter boat anglers per fishing day was 3.5 cod in 2014. The total number of German anglers fishing in the Baltic Sea was estimated at around 156,000 with a total effort of approximately 1.1 million fishing days. The estimated cod catch (harvested fish and dead releases) was **2 891 t compared to 3 243 t of cod** landed by the **German commercial fishery** in 2014 (approximately 47% of the total German landings). If these data are excluded from assessments, it is not possible to quantify all human impacts on stocks and this jeopardizes our ability to achieve MSY (ICES, 2015a). Further recreational fisheries could be impacting **local stocks** or stock components, as well as **endangered/threatened species**. Moreover, recreational fisheries for particular species may become more or less important over time, e.g. the increasing trolling fishery for Baltic salmon. In a situation where the recreational fisheries have a large component of **young fish**, the catch in numbers could be large although the **catch weight is small**. And last, in a situation of overfishing **recreational fishing mortality** – if the known magnitude is large enough –

may prevent recovery of depleted stocks. The availability of time-series data is important to show trends and support evidence-based decision making.

2.2. Use of recreational fisheries data

The regular collection of recreational fishery data in Europe started in 2001²⁰ (CEC, 2001). The relevant species for which recreational data needs to be collected have been laid out in EU Data Collection Regulations²¹ (CEC, 2008; 2010; 2013a, b). It is recommended that existing recreational surveys collecting only **single species** data should be extended collecting data for **multiple species**, as it is generally easy to collect multiple species within the same survey program without significantly greater costs (ICES, 2015a). Up until now “the persistent lack of reliable **catch estimates** of European marine recreational fisheries remains one of the **biggest challenges** for stock assessments and fisheries managers today” (Eero *et al.*, 2014). Many national surveys are still incomplete or lacking completely, making it difficult to understand the relative pressures and impacts of all fisheries in a region (ICES, 2015a). Further challenges arise from the inconsistency of data over time and an unclear understanding of catch, which includes harvested and released components. ICES (2015b) has identified the following main drivers for collection of recreational fisheries data:

- i) **Advice on fishing opportunities.** The need to quantify the total removals from a stock in order to give accurate advice on the fishing opportunities currently drives most of the collection of recreational fishery data;
- ii) **Design and evaluation of management measures.** Where there is a need for specific management measures for recreational fisheries, the development and evaluation of the measures requires information on the characteristics of the fisheries concerned;
- iii) **Development and evaluation of management plans/strategies involving recreational fisheries.** The development of fisheries management plans or strategies for a stock should include recreational catches where they are relevant for achieving management objectives;
- iv) **Marine spatial planning**²². There is a need for information to support marine spatial planning in areas where recreational fisheries compete for space with other users of the marine environment.

2.3. Relevant species in the Baltic Sea

The following **three species** have been identified as those where the recreational fishery is responsible for a large share of the total fishing mortality in the Baltic Sea. However, this list is not exhaustive and there are other species and stocks where recreational catch is a considerable component of the total catch but statistical estimates are not available or currently unknown.

²⁰ CEC (2001), *Council Regulation (EC) No. 1639/2001 of 25 July 2001 establishing the minimum and extended Community programmes for the collection of data in the fisheries sector and laying down detailed rules for the application of Council Regulation (EC) No. 1543/2000*. Official Journal of the European Communities EN2001.

²¹ CEC (2008), *Commission Decision 2008/949/EC of 6 November 2008 adopting a multiannual Community programme pursuant to Council Regulation (EC) No 199/2008 establishing a Community framework for the collection, management and use of data in the fisheries sector and support for scientific advice regarding the common fisheries policy*.

CEC (2010), *Commission Decision 2010/93/EU of 18 December 2009 adopting a multiannual Community programme for the collection, management and use of data in the fisheries sector for the period 2011-2013*.

CEC (2013a), *Commission Implementing Decision of 13.8.2013 extending the multiannual Union programme for the collection, management and use of data in the fisheries sector for the period 2011-2013 to the period 2014-2016*.

CEC (2013b), *Regulation (EU) No 1380/2013 of the European Parliament and the council of 11 December 2013 on the Common Fisheries Policy, amending Council Regulations (EC) No 1954/2003 and (EC) No 1224/2009 and repealing Council Regulations (EC) No 2371/2002 and (EC) No 639/2004 and Council Decision 2004/585/EU*.

²² *Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive)*.

Baltic cod

National marine recreational fisheries surveys showed that the recreational fishery removes considerable amounts of biomass from the western Baltic cod stock (ICES, 2015a; Sparrevohn and Storr-Paulsen, 2012; Strehlow *et al.*, 2012). In recent years, western Baltic cod has experienced considerable declines and is presently estimated to be at historically low biomass levels and below the limit reference point Blim (ICES, 2015c). The current recreational catch accounted for **25%** of the total catch in 2014 (**8 099 t commercial + 452 t discards + 2891 t recreational**) and is considered a minimum estimate as it only includes German data (ICES, 2015c). The European Council highlights that Baltic Member States agreed to improve their data collection systems to include recreational fishery data into International Council for the Exploration of the Sea (ICES) assessments.

Baltic salmon

Harvest rates of Baltic salmon have **decreased** considerably since the beginning of the 1990s. As basis for MSY the status of wild stocks is assessed using the potential smolt production capacity (PSPC) for each river. The reference points are reached when PSPC is above 75%. In 2014 the overall PSPC of salmon stocks was 65%, however only five of the 40 assessed stocks had reached 75% of the PSPC (ICES, 2015d). Recreational catch estimates of Baltic salmon in freshwater and marine habitats have been included in the assessment for many years. However, **catch estimates** of the recreational salmon fishery are **uncertain**, incomplete or missing for several Member States. Currently, recreational fishing is thought to **take 13%** of the **total marine catch**, but this is likely to change as better estimates become available (ICES, 2015d). In particular, the impacts of the growing recreational trolling fisheries in the Baltic Sea are likely to be underestimated making it difficult to assess its effect on the recovery of weak salmon stocks.

Baltic sea trout

Due to concerns about the status of Baltic sea trout populations, an assessment was established and carried out in 2012 and updated in 2015 (ICES, 2015d). In general, sea trout populations are in a lower than optimal state in most of the Baltic Sea (ICES, 2015d). Bothnian Bay stocks are seriously endangered, while a good stock status is only found in the western Baltic Sea and in part of the Gulf of Finland (ICES, 2015d). These stocks are not total allowable catch (TAC) managed, MSY proxies still need to be determined. Parr abundance adjusted with habitat quality and water chemistry is used to assess individual sea trout populations (ICES, 2012c). Baltic Sea trout is a popular target species in the recreational fishery. Recreational catches are known with little accuracy and are substantially underestimated (ICES, 2015d). In 2012 recreational catches were much larger than commercial catches (429,6 t recreational + 281,3 t commercial). The majority of recreational catches is taken in coastal waters and to a lesser extent by the recreational fishery in rivers (*cf.* ICES, 2009; 2015d).

Populations of diadromous species such as Baltic salmon and sea trout (species that spawn in rivers and use the sea as adults) are also affected by **other human activities** influencing freshwater habitats, mostly through **damming, dredging, pollution** and **siltation** of rivers (ICES, 2015d). Consequently, ICES is recommending habitat restoration, removal of migration barriers and improvement of the water quality (ICES, 2015d).

2.4. Releasing fish under the Landing Obligation

Although large components of recreational catches are kept, substantial proportions are **released alive** either due to regulations or voluntarily (released fish that legally could have been retained; Ferter *et al.*, 2013). Overall release proportions by weight in the Baltic Sea ranged from 29–70%, with the exception of Poland where only 1% of the recreational cod catch is released (Ferder *et al.*, 2013). Exemplary release proportions for cod were 29%

(Germany), for sea trout 70% (Denmark) and for salmon 36% (Sweden, marine waters; Ferter *et al.*, 2013). From a management perspective it is important to quantify **post-release** mortality and evaluate other potential sub-lethal effects of the catch. Both are needed to obtain accurate catch estimates and determine if this would impact the sustainable management of fish stocks. This may be particularly relevant for **unwanted catch or species captured incidentally** (e.g. protected species) but there is no evidence that this is of any importance in the Baltic Sea. For Baltic cod we demonstrated that nearly **90%** of the **fish survived** after being released back into the sea (Weltersbach and Strehlow, 2013), indicating that fisheries management and conservation objectives are supported and recreational fisheries releases are reconcilable with the new CFP. However, presently there are no post-release mortality estimates available for sea trout and salmon.

2.5. Economic and social benefits

Marine recreational fishing is an integral part of European coastal life and communities, with more than **8 million anglers** spending over **€8 billion every year** and with a continuous growth of the sector at large (Pawson *et al.*, 2008). Economic data is particularly useful for managers to help manage the resource efficiently. A study by the Thünen Institute of Baltic Sea Fisheries estimated the total annual expenditure of the German marine recreational fisheries in the Baltic Sea at **112 million euros** (unpublished data). This money is often spent in the coastal communities contributing to local employment such as tackle shops, hotels, restaurants, boat and equipment rentals, charter boats and fishing guides, for example. The recreational sector does not only contribute economically but also provides **social benefits** to society like relaxation, exercise and experience of nature. Further, recreational fishers often collaborate with scientists as citizen scientists collecting biological catch data (length, weight, tissue samples) that helps contribute to the evidence-base and thus to the sustainable management of stocks.

2.6. Managing recreational catch

Including recreational mortality into assessment models inevitably challenges management regarding the **allocation of resources** between the **commercial** and the **recreational** sector. However, unlike in the US, there is currently no management framework in the EU that **balances** the interests of both sectors. Moreover, allocation decision should not only be based on historical harvest patterns and economic principles but also take into account fairness and equity (Eero *et al.*, 2014). Once the managers have decided, the TAC may be set to either (i) correspond to the total catch including commercial catch and recreational estimates, or (ii) the TAC can be provided for the commercial sector only, as is currently done for western Baltic cod (ICES, 2013).

In a situation where there is a need to reduce the overall fishing mortality, the recreational fishery may also require management actions (Eero *et al.*, 2014). Thereby managers should keep in mind that **recreational management objectives** are more about angling quality than yield per recruit, thus the fishing effort that produces MSY may differ from the level providing maximum total satisfaction (Cox *et al.*, 2003; Hussain and Tschirhart, 2010; Pereira and Hansen, 2003; Post and Parkinson, 2012; Radomski, 2003). Consequently, marine recreational fishery stakeholders should be included in advisory councils to incorporate their management goals. Management measures that imply very large annual **reductions of fishing** opportunities to achieve MSY and include the recreational sector should make sure not to jeopardize the social and economic sustainability of the sector at large. Marine recreational fisheries are under **jurisdiction** of the individual **Member States** (in Germany: individual federal states). Therefore, multiple management measures are in place with no regional or national coordination.

In general, the following regulations are commonly used to manage the marine recreational fishery in the Baltic Sea:

- **Minimum landing sizes (MLS)** are commonly used and apart from the indicative minimum conservation reference size it is up to the individual Member States to choose different MLS. Accordingly, captured fish under the MLS is released back into the sea.
- **Bag limits** restrict recreational fishers to keep only a certain number of individual fish per day. This form of harvest regulation is commonly used for salmonids in the Baltic Sea.
- **Closed seasons** are applicable for several recreational target species in the Baltic Sea. Again individual regulations may differ locally and between Member States. Unlike in the commercial fishery recreational fishers are still allowed to fish but will need to release their entire catch for those species restrictions apply for.
- **Closed areas** define areas that are closed for recreational fishing to aid the conservation of stocks and preservation of sensitive habitats. Commonly found regulations restrict the allowable fishing distance to commercial fishing gear to prevent conflicts. Other non-take areas are designed to protect spawning migrations (estuaries or river mouths) and/or overwintering aggregations. To design and/or evaluate closed areas, higher resolution data as usually available from recreational fishing surveys may be needed.
- **Gear restrictions** regulate the number of fishing rods per angler, number of hooks per rod, as well as number of passive gear for recreational fishers. Many different regulations apply for the Baltic Sea.

Similar to commercial fisheries it is important that if MSY objectives are to be achieved, recreational fishers adhere to regulations regarding **catch retention**, e.g. MLS or bag limits. And similar to the commercial sector there is a problem with adherence to harvest regulations among the participants in the recreational fishery. However, the level of non-compliance is fishery-specific and difficult to assess.

The **availability** of marine recreational fishery **data** is **crucial** to design and evaluate effective recreational management measures. It is similarly important to understand the behavioural responses of recreational fishers to regulatory policies. As recreational effort is not necessarily driven by catchability – since recreational fishers not only value catch but also other ecosystem services and are not constrained economically – this may lead to unexpected outcomes. For example, lower bag limits may induce higher fishing effort if more catch-oriented fishers compensate for reduced harvest or lead to a reallocation of effort to other fish species. This dynamic is further complicated as the recreational fisheries differ substantially between Member States in terms of participation rates, effort, catch rates, motivation (e.g. social interaction, sport), and consumptive orientation (*cf.* Griffiths *et al.*, 2016). As a result, there is **no “one-size fits all”** management. Management measures must be tailored to the individual Member States and their fisheries. Therefore, managers are charged with the difficult task of developing a **regional** perspective to sustainable recreational fisheries management taking into account the heterogeneity of recreational fisher populations (Lester *et al.*, 2003). When recreational catch is poorly known, sensitivity analyses or management strategy evaluation methods could be useful to explore the effects of uncertainty in catch information.

3. IMPACTS OF OTHER HUMAN ACTIVITIES ON COMMERCIAL FISH STOCKS: OTHER ANTHROPOGENIC FACTORS

KEY FINDINGS

- **Stock development depends** not only on fisheries management, but also **on the ecological status of marine ecosystems**.
- Increasing human uses and climate change put **increasing pressure** especially **on coastal habitats**.
- **Eutrophication is still a major issue in the Baltic Sea** inducing hypoxia with massive effects on total fish abundance and communities.
- **Reductions of toxic pollutants** in the Baltic Sea have been a success story. **However, legacy pollution maintains** concentrations of some substances **at levels of concern** and for some substances no advances have been made.
- Coastal degradation affects many fish stocks during their life cycle. High level of **coastal degradation in the Baltic Sea calls for a protection of the remaining pristine habitats**.
- **Non-indigenous species affect ecosystem functioning**, however, the level of impact is often unknown. Ecosystem-based management should integrate non-indigenous species and their interactions with other drivers.
- **Climate change exacerbates the already high stress on the marine environment** and is changing Baltic fish communities. Accordingly, **future management needs to be flexible and management targets continuously adjusted**.
- There is a **disconnect and fragmentation of institutional arrangements** and management bodies responsible for various environmental problems and the ecological functioning of coastal areas affected. **A sustainable ecosystem-based management should better integrate environmental concerns into the Common Fisheries Policy (CFP)** and facilitate coherence between the different policies.

Next to commercial and recreational fisheries there are other human-induced factors impacting coastal-marine ecosystems. **In 2003**, worldwide, more than **1.2 billion people** were living within 100km of the coast, with average densities nearly three times higher than global average densities (Small and Nicholls, 2003). Anthropogenic stressors such as eutrophication, pollution, coastal modification, species introduction, and **climate change** are increasingly threatening the living resources that depend upon the coastal-marine habitats (Doney, 2010; Hughes *et al.*, 2015; Rabalais, 2015). Stricter adherence to scientific advice and fishing mortality levels set at maximum sustainable yield (MSY) has resulted in a more sustainable fisheries management. However, there are examples where stocks have not responded to reduced fishing mortality and management strategies are failing to reach their objectives. Future management should include **good environmental status** of marine habitats as a prerequisite for productive fish stocks in an attempt to develop a true ecosystem-based management (Elmgren *et al.*, 2015). Examples include **integrated** coastal zone management coupled with extensive environmental monitoring of ecological effects (Andersen *et al.*, 2015).

In the Baltic Sea, massive environmental problems in the 1960s led to the creation of the Helsinki Convention for the Protection of the Marine Environment in the Baltic Sea Area with its governing body HELCOM (Baltic Marine Environment Protection Commission - Helsinki Commission). Unlike other large marine ecosystems in Europe, environmental impacts are more pronounced in the Baltic Sea due to its huge catchment area and limited water exchange (Elmgren *et al.*, 2015).

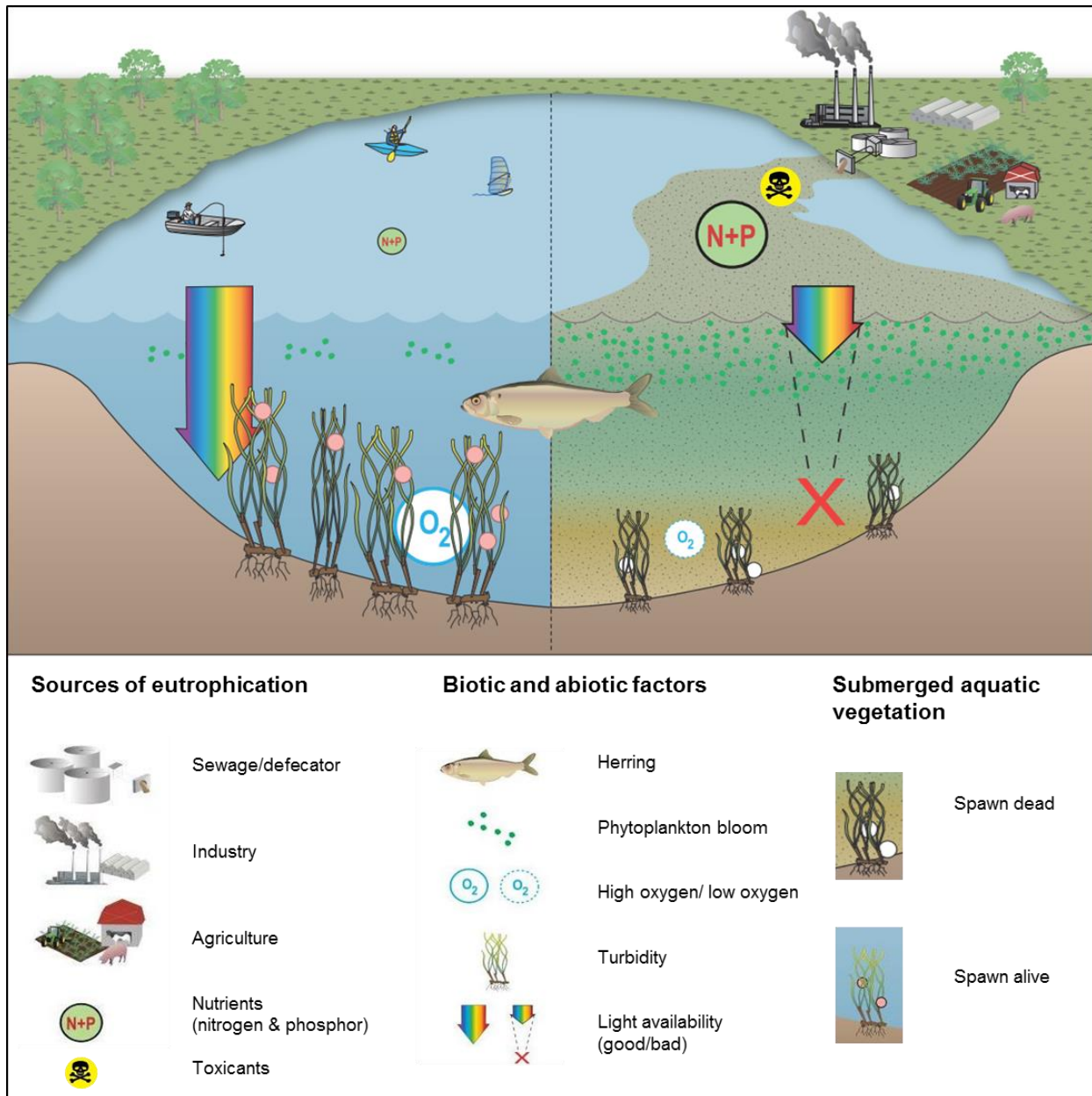
3.1. Eutrophication

Although success has been made reducing nutrient inflows in the previous decades due to the reduction of point source discharges, e.g. installation of sewage systems with improved wastewater treatment, there are still issues concerning **nutrient inflows** from diffuse sources (Elmgren *et al.*, 2015). Long-term observation of nutrient concentrations caused by anthropogenic activities showed an increase in eutrophication which is only slowly levelling off (Feistel *et al.*, 2008) and a recent assessment found that the eutrophication status was unacceptable in all 17 open sea basins of the Baltic Sea (Fleming-Lehtinen *et al.*, 2015).

Eutrophication is a condition of high nutrient concentrations – mainly nitrogen (N) and phosphorus (P) but also organic matter (C, carbon) – stimulating algae growth often leading to an **imbalance** of the aquatic ecosystem (HELCOM, 2005). High nutrient loads come from airborne discharge originating from emissions to the air and waterborne input from diffuse sources resulting from agriculture (Feistel *et al.*, 2008). A considerable amount of P is further accumulated in muddy sediments, with a high potential for resuspension, especially in the shallow waters characterizing the Baltic Sea (Andersen *et al.*, 2015). The increased concentrations result in massive phytoplankton and zooplankton growth leading to increased water turbidity and consequently decreased light availability for submerged aquatic vegetation such as seagrass. The decomposition of the organic matter depletes oxygen levels (a condition known as hypoxia) making eutrophication one of the strongest drivers of hypoxia (Conley *et al.*, 2009) and the Baltic Sea the area with **the largest contiguous oxygen-free zone of the world**. The negative impacts of poor water quality and **hypoxia effect** total fish abundance and communities, particularly in the Baltic Sea (Österblom *et al.*, 2007; Snickars *et al.*, 2015). The complex relationships between the input of nutrients and their influence on marine ecosystems are shown in Figure Scientists have come to the conclusion that reduction of hypoxia in the Baltic Sea will only occur if nutrient loads are reduced (Conley *et al.*, 2009; Wulff *et al.*, 2007).

Here a discrepancy becomes apparent between **polluters** and the level of impact symbolized through the land-sea interface (e.g. Hughes *et al.*, 2015). This land-water boundary needs to be overcome (e.g. disconnect of institutional arrangements and management bodies that do not take into account the **ecological functioning** of coastal areas as spawning and nursery grounds) if political agreements on effluent reduction are to be effective (*cf.* Elmgren, 2001; Elmgren *et al.*, 2015).

Figure 2: The impact of eutrophication, illustrated by an exemplary case, on the spawning habitat of western Baltic herring.



Source: D Moll; symbols courtesy of ian.umces.edu/symbols/

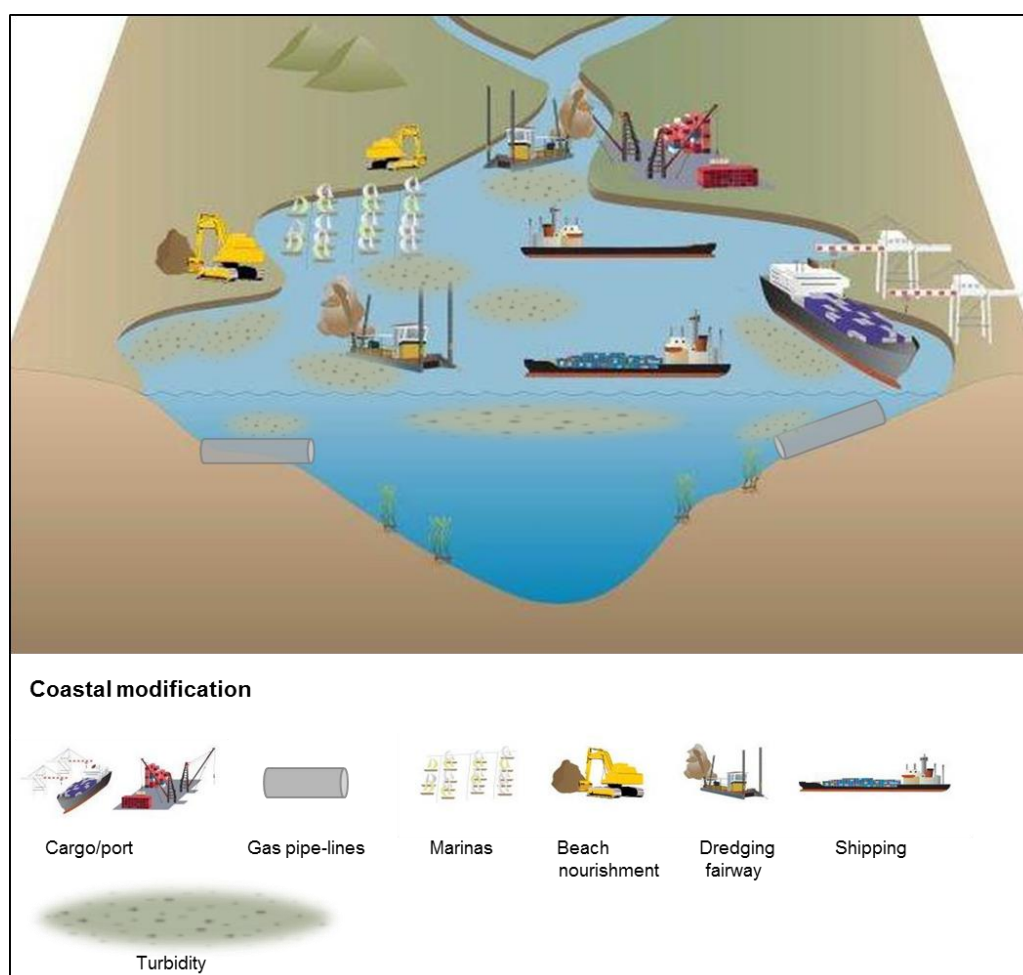
3.2. Pollution

Coastal and marine pollution cause **serious threats** for the health of marine organisms and human beings (Islam and Tanaka, 2004). Pollutant discharge comes from **pulp and paper mills, agricultural and urban runoff, oil spills, untreated sewage**, etc. (Islam and Tanaka, 2004). Pollutants accumulate in coastal sediments and have a high persistence. The major contaminants are heavy metals and persistent organic pollutants (POPs), such as DDT (dichlorodiphenyltrichloroethane), PCBs (polychlorinated biphenyls) and dioxins for example. In the Baltic Sea considerable advances have been made reducing toxic pollutants. Nevertheless, dioxin concentrations in fish from parts of the Baltic remain above EU threshold values and "legacy pollution maintains concentrations of some substances at levels of concern" (Elmgren *et al.*, 2015). Besides accumulating in marine organisms, pollutants may impair reproduction functions of fish (Islam and Tanaka, 2004).

3.3. Coastal modification

Coastal modification and development **encompasses** a number of human activities such as **shoreline constructions (ports, jetties and marinas), dredging of fairways, construction of gas pipelines, beach nourishment**, etc. (Figure). Coastal modification can severely affect habitats and biodiversity both in coastal ecosystems and in deeper regions (Sundblad and Bergström, 2014). The associated stress caused by suspended sediments and turbidity can affect fish populations in many different ways (Kjelland *et al.*, 2015). A recent assessment demonstrated that 44% of the species for which advice is given by (International Council for the Exploration of the Sea) utilize coastal habitats during some time of their life cycle, and these stocks contributed 77% of the commercial landings of ICES-advice species, emphasizing the ecological value of **coastal habitats** (Seitz *et al.*, 2014). A study carried out in the Stockholm archipelago in the Baltic Sea estimated that “approximately **40%** of available habitats were already degraded in 2005” (Sundblad and Bergström, 2014).

Figure 2: Forms of coastal modification.



Source: D Moll; symbols courtesy of ian.umces.edu/symbols/

3.4. Species introduction

The introduction and establishment of **non-indigenous species** may substantially alter local biodiversity and ecosystem functioning (Ojaveer and Kotta, 2014). A recent literature review found that of 18 widespread established non-indigenous species an ecological impact was observed for 13, among them round goby (*Neogobius melanostomus*) and the comb jelly *Mnemiopsis leidyi* (Ojaveer and Kotta, 2014). However, there is little available knowledge on the nature and magnitude of impacts (Ojaveer and Kotta, 2014). Instead of focusing on a

single invader, we should integrate **non-invasive species** into an ecosystem approach to management also considering the **interactions** with other drivers (Strayer, 2012).

3.5. Climate change

Climate change exacerbates the **anthropogenic stressors** mentioned above increasing the already high levels of stress on fish stocks and the marine environment (Snickars *et al.*, 2014)). Projected warming in the Baltic Sea is expected to be higher than in other marine areas (Elmgren *et al.*, 2015). Warmer sea water dissolves less oxygen, thus, it is likely that the interaction between climate and eutrophication will enhance the conditions for hypoxia to occur (Conley *et al.*, 2015). In northern Europe climate change will also lead to increased precipitation with cascading effects resulting in decreased photic depth and salinity (Snickars *et al.*, 2014). Increasing **temperature** and decreasing **salinity** as predicted by climate change scenarios suggest declining trends of **zooplankton** in deeper water and potential food shortage for benthic-feeding fish such as cod (Snickars *et al.*, 2014). And a long-term **data analysis** of coastal fish communities during four decades in the Baltic Sea revealed that there was an “overall transition from communities dominated by marine species and those favoured by cold water to a state characterized by species of a freshwater origin in favour of warmer waters” (Olsson *et al.*, 2012). **Changes** in fish communities caused by climate change, altered productivity or changes in species interactions will require a **flexible management**, where management targets are continuously adjusted (Olsson *et al.*, 2012).

4. MAIN IMPACTS OF THE LANDING OBLIGATION ON THE ECOSYSTEM

KEY FINDINGS

- The Landing Obligation aims at changing the current practice of discarding. The entire catch (**landings plus previous discards**) of total allowable catch (TAC) species **has to be landed**.
- **In the Baltic Sea, the Landing Obligation applies to** one demersal species (**cod** *Gadus morhua*) and three pelagic species (**herring** *Clupea harengus*, **sprat** *Sprattus sprattus*, and **salmon** *Salmo salar*). **Plaice** (*Pleuronectes platessa*) will be covered from 2017 onwards.
- Of these species, **only cod and plaice cause relevant amounts of discards**. Discards of the other species are either very small (salmon) or negligible (herring and sprat).
- The **Landing Obligation is not fully implemented yet** and actual figures are missing or incomplete. Therefore, **potential effects are demonstrated exemplarily** using assessment data from 2014.
- The exercise revealed that the Landing Obligation would result in **landing of little additional biomass (around 2%) when compared to the total landings** from the Baltic Sea in 2014.
- Considerable amounts of **non-TAC and bycatch species** will be **still discarded**, e.g. all flatfish species except plaice, as well as benthic invertebrates, seabirds and marine mammals.
- Scavenging on discards by seabirds is widespread in the Baltic Sea, however, the number of seabird species feeding on discards is generally lower than in other EU waters. **Gulls are the most numerous scavengers** (mainly herring gull *Larus argentatus*). **Adverse large-scale effects of the Landing Obligation on scavenging seabird populations are unlikely**, but local effects in certain areas cannot be excluded.
- The **role and importance of discards and offal for benthic communities in the Baltic Sea is largely unclear**.

Fishing activities are one of the most widespread human uses of the sea and can cause various impacts of different intensities on marine environments and species (Goñi, 1998). One of these impacts is caused by the **bycatch of unwanted species and sizes** that are **discarded at sea**. Discards are a source of energy that is removed and immediately returned to the marine ecosystem (Sardà *et al.*, 2015). The EU's Landing Obligation aims at **changing** the current practice of discarding. The entire catch (landings plus previous discards) of TAC species has to be landed so that **undersized specimens are no longer returned to the sea**.

This chapter addresses the potential consequences for the marine ecosystem of the **extra removal of biomass**. As a first step, we relate this biomass to a) the total commercial landings from the Baltic Sea, and b) the biomass that will continue to be returned to the sea (this involves discards (e.g. **undersized specimens of non-TAC species**) and **offal** (i.e. remains of gutted round fish like cod)).

4.1. Discards

In the Baltic Sea the Landing Obligation will apply to **one demersal species** (cod *Gadus morhua*) and **three pelagic species** (herring *Clupea harengus*, sprat *Sprattus sprattus*, and salmon *Salmo salar*). Plaice (*Pleuronectes platessa*) will be covered from 2017 onwards.

As the Landing Obligation is not fully implemented yet, actual figures are **missing**. Therefore, potential effects are demonstrated exemplarily using assessment data from 2014, when most recent estimates were produced (Table 7). This implies that for cod a minimum landing size (MLS) of 38 cm is used and fishing patterns are assumed constant (e.g. no changes in fishing by the skippers to avoid bycatch). Therefore, bycatch and **discard** estimates should be considered **maximum estimates**. Moreover, it is of note that total and relative amounts of discards are heterogeneously distributed in space and time, and are also highly variable between years (e.g. due to natural variations in recruitment).

In 2014, when the **Landing Obligation** was **not in place** yet, about **21 487 t** of fish biomass was **discarded** (Table 7). Once the Landing Obligation is in place, from this amount one third (**33%**) will continue to be legally discarded at sea (mainly **non-TAC flatfishes**) while two third (67%) have to be landed. However, when compared to the total landings from the Baltic Sea, the Landing Obligation would result in landing of little additional biomass, only around 2%.

4.2. Offal

Unlike flatfishes, cod and salmon (and other round fish) are processed on board the fishing vessels in the Baltic Sea. This is a legal provision due to **food safety issues** (e.g. parasites that may move from the intestines into the flesh). The remains of the gutting are called offal and discarded at sea. Under the LO, **market-sized cod** (larger than the minimum conservation reference size (MCRS)) still have to be gutted at sea while cod smaller than the MCRS have to be landed whole (i.e. ungutted). Thus, remarkable amounts of **offal** will continue to be provided to **scavengers**. When applying an estimated proportion of offal of 14.7% for cod (ICES, 2000) to the most recent landing data of cod, more than 6 000 t of offal incurred in 2014. It is important to note that this is **more than half (53%)** of the amount of total **cod discards** in the year **2014** (Table 7). In the Baltic Sea, the total amount of offal originates nearly exclusively from the gutting of cod, the amount of offal from gutting other fish species is insignificant (ICES, 2000). Offal constitutes a major food subsidy to scavenging species like seabirds (Tasker *et al.*, 2000, Garthe and Scherp, 2003, Furness *et al.*, 2007).

Table 7: Hypothetical example applying the Landing Obligation to 2014 fisheries data from the Baltic Sea. Offal: waste from gutted fish disposed at sea; assuming 14.7% of offal for whole cod (ICES, 2000).

FISH STOCK	LANDINGS	BYCATCH			OFFAL	BYCATCH + OFFAL	OFFAL
		NOT COVERED BY LO	LANDED UNDER LO				
(ICES subdivisions in the Baltic Sea)	(tons)	(tons)	(tons)	(% total catch)	(tons)	(tons)	(% bycatch + offal)
Cod 22-24	8 000		500	6	1 176	1 676	70
Cod 25-32	34 347		11 309	25	5 049	16 358	31
Salmon 22-31	1 022		54	5	(3)		
Salmon 32	95		6	6	(3)		
Plaice 21-23	1 931		1 956	50	(3)		
Plaice 24-32	534		481	47	(3)		
Flounder 22-23	1 193	540		31	(3)		
Flounder 24-25	14 610	5 874		29	(3)		
Flounder 26, 28	4 614	(1)			(3)		
Dab	1 269	757		37	(3)		
Brill	28	4			(3)		
Turbot	253	(1)			(3)		
Sea Trout	219	(2)			(3)		
Herring 3a & 22-32	312 032		(3)		(3)		
Sprat	244 000		(3)		(3)		
Sum	624 147	7 175	14 312		6 225	27 712	23
		21 487					

Source: Last available stock and discard data (ICES, 2015c, ICES, 2015e).

Note: Discard calculation is based on a MLS/MCRS of 38 cm (MLS until 31.12.2014), and no adaptation of fishing pattern is assumed. Bycatches should therefore be considered maximum estimates.

(1) considered substantial, but not quantifiable; (2) no estimates; (3) negligible

4.3. Effects of discards on seabirds

Discards, especially fish, are a major food source for many scavenging **sea birds**, marine mammals, **fish and benthic invertebrates** (Garthe and Scherp, 2003, Bicknell *et al.*, 2013, Kaiser and Hiddink, 2007, Furness *et al.*, 2007). The decrease in fish biomass caught and provided by fishers to scavengers is assumed to reduce **food availability for scavengers** and might affect the equilibrium of existing species interactions (Veiga *et al.*, 2016). The **Landing Obligation** may also affect the **marine-coastal environment** and communities of certain species in the world's largest brackish water sea.

Scavenging on discards by seabirds is widespread in the Baltic Sea. However, the number of seabird species feeding on discards is lower than in other marine regions (Garthe and Scherp 2003). **Herring gull** (*Larus argentatus*) is the most abundant scavenging species in all Baltic areas and seasons, followed by great black-backed gull (*Larus marinus*) and lesser black-backed gull (*Larus fuscus*) as well as mew gull (*Larus canus*) (Garthe and Scherp, 2003). For other **common seabird** species in the Baltic Sea, like **great cormorant** (*Phalacrocorax carbo*) and common guillemot (*Uria aalge*) discards and offal are not important (Tasker *et al.*, 2000, Garthe and Scherp, 2003). Other scavenging seabird species typical for the North Sea, like gannet (*Morus bassanus*) or northern fulmar (*Fulmaris glacialis*), do not occur in the Baltic Sea or at very low numbers (Garthe and Scherp, 2003).

Analysis of herring gull pellets demonstrated differences in the importance of **offal** in the **diet**, depending on the region and season (Garthe and Scherp, 2003). Experiments showed that herring gulls mainly ingested discarded cod, preferably specimens smaller than 30 cm. Gulls did not take discards of flatfish species like plaice (*Pleuronectes platessa*) and flounder (*Platichthys flesus*); only dab (*Limanda limanda*) was taken but at very low rates (Garthe and Scherp, 2003).

Generally, it is difficult to unambiguously demonstrate **effects of fisheries on seabird** population abundance because adverse or beneficial effects can be caused by numerous factors at multiple spatial and temporal scales (Tasker *et al.*, 2000). Moreover, it is problematic to predict the response of seabird communities to changes in discard rates because historical baseline data would be needed to elucidate the confounding effects of other, more 'natural' ecological processes (Votier *et al.*, 2004). Most scavengers are **opportunistic** by nature. For instance, **herring gulls** – listed as of "least concern" in the most recent **Red List of Baltic Sea bird species** (HELCOM, 2012) – also use **other** anthropogenic **food sources** like refuse dump sites (Markones and Guse, 2007, Capandegui, 2006). Hence, the effects of changes in terrestrial dump site access on herring gull population dynamics could be confounded with LO-induced changes in marine food supply, or other factors.

The population dynamics of lesser black-backed gulls is probably affected by changes in trawler discard availability in the western Mediterranean (Oro, 1996). Two sub-species of lesser **black-backed gull** (*Larus fuscus* ssp.) live in the Baltic and were assessed separately in the most recent Red List of seabirds in the Baltic (HELCOM, 2012). The sub-species *L. fuscus intermedius*, that breeds in the western Baltic (Denmark, Swedish west coast, recently also in Germany) is of least concern. In contrast, the nominate sub-species *L. fuscus fuscus* that breeds in the central and eastern Baltic Sea and eastern Scandinavia (Map 3) is listed as vulnerable. There are some indications that the size of *L. f. fuscus* population at the east coast of **Sweden** is related to the presence of sprat, but a detailed study could not reveal starvation of chicks as a reason for low breeding success in this area (Capandegui, 2006). However, **herring gulls** prey on chicks of *L. fuscus fuscus* and it cannot be ruled out that food shortage caused by lower fish stocks and/or lower discard rates might increase the predation pressure of herring gulls on *L. fuscus fuscus*. Such switching of prey by the **great skua** (*Stercorarius skua*) as a facultative scavenger in case of **food shortage** was demonstrated to be a potentially serious threat to some seabird communities in the North Sea (Votier *et al.*, 2004). Yet, Bicknell *et al.* (2013) stated that it seems unlikely that decreasing **discard rates** could cause a crisis for most seabird populations. In addition, offal would still be available as food source (see above).

Map 3: Distribution of lesser black backed gull subspecies *Larus fuscus fuscus* in the central and eastern Baltic Sea.



Source: HELCOM (2012)

4.4. Effects of discards on benthos

Seabirds display remarkable efficient and **selective consumption** near fishing vessels. They influence strongly how much discards and offal reach the benthic scavenger communities (Furness *et al.*, 2007). For example, in the Baltic normally most of discards and offal are eaten by seabirds (Garthe and Scherp, 2003). The remains may be partly eaten by opportunistic fishes in **the water column** before touchdown at the seabed. However, few studies are available (Furness *et al.*, 2007) and the role and importance of discards and offal for benthic communities in the Baltic Sea is **virtually unknown**.

5. IMPLEMENTATION ERROR

KEY FINDINGS

- Fisheries management has often **failed to achieve the intended level of exploitation** of the resource; this is called **implementation error**.
- Under **landings quotas** the fishing mortality rates are not limited, causing **implementation error**. In contrast, under **catch quotas** (landings plus discards) this source of **implementation error is avoided**, but only if all catches of quota species are **accounted** for.
- Full catch accountability can be achieved by **remote electronic monitoring and closed circuit television (CCTV)** – this is called **fully documented fishery (FDF)**.
- A **quid-pro-quo** approach, or **tiered approach**, would be that groups of fishers (or Member States) deploying **FDF are entitled to catch their full quota shares**, whereas groups of fishers (or Member States) **without FDF** would be assumed to discard; these **assumed discards would be subtracted from their quota share**.
- **Behavioural science** suggests that some of the past **implementation error** may have been caused because **the complex top-down control** and **lack of trust** have **undermined** fishers' potential **intrinsic motivation** to fish sustainably.
- **Compliance** is **not** necessarily a **function** of the **economical pros and cons** of rule violation: compliance may be higher or lower, depending on intrinsic motivations. **Monetary incentives** may **undermine** such motivations.
- An increased level of **self-decision** may lead to **more buy-in** to sustainable fishing practices and **voluntary compliance** to catch limits and the Landing Obligation.
- All else being equal, people in **small and self-selected groups** are inherently more likely to **behave "prosocial"**.
- In this chapter some key **recommendations** based on **behavioural science** are given **for changes**, e.g. in institutional settings, that may **increase voluntary compliance** and **sustainable fishing practices**. However, **transition** to a system allowing for more freedom from top-down regulation, with more self-governance, may be **difficult** and may **take many years**.

Fisheries **management** has often **failed** to achieve the intended level of exploitation of the resource; this is called implementation error. "Implementation error is usually regarded as falling outside the scientific component of fisheries management and although very much in evidence, has been little studied (O'Boyle, 1993). It is largely the failure to **control exploitation** by whatever **MCS (monitoring, control and surveillance)** measures have been adopted. The reasons are many and interrelated, for example, poor surveillance and enforcement, lack of concern by the **judiciary** when **cases** are heard, failure of participants to support measures due to lack of opportunity for input during their development or simply disagreement with the measures enforced" (Caddy and Mahon, 1995). In management systems which are based primarily on advice from biological assessments, failure to incorporate, or incorrect incorporation of **non-biological information**, also contribute to implementation error. These problems may frequently be known to the managers and their technical advisers, but it may be impossible to quantify the uncertainty, except in retrospect. "A workshop to review management of groundfish stocks on the Scotian Shelf off eastern Canada from 1977 to 1993 concluded that implementation error was the primary cause of the failure to conserve stocks (Angel *et al.*, 1994). The workshop noted that '*In sum, the tactical*

approach chosen to control fishing mortality generated illegal behaviour which was not curbed by the available enforcement regime' " (Caddy and Mahon, 1995).

Minimizing implementation error is therefore as important as the accurate estimation of the required target fishing mortality and catch limits for the "ensuring that catch limits maintain populations of harvested stocks to levels which can produce the maximum sustainable yield (MSY)". Implementation error has contributed to a large extent to past **failures** of fisheries **management**. Therefore, an analysis of **factors** underlying implementation error is necessary. In order to minimize overlap with the report to the European Parliament (EP) by Hedley and Catchpole (2015), we refer to that report for more detailed accounts on monitoring and control, enforcement and compliance, remote electronic monitoring (REM) and (FDF), and concerns for increased black market trade for juvenile fish.

Prior to the Landing Obligation, the main instrument to control fishing pressure in the EU has been the setting of Total Allowable **Landings quotas**. This instrument has allowed for **implementation error** because landings quotas do not limit **catches**. Under landings quotas, unlimited **overquota catches** are allowed as long as they are not landed; in other words, they must be discarded at sea. There are **three major reasons for discarding**: **(1)** fish smaller than the **minimum landing size (MLS)** are not allowed to be landed; **(2)** fishers may discard **lower-quality** fish and utilise their landings quota to land better-quality fish (high-grading); this practice is forbidden since 2002 but no offenders have been caught and sanctioned (Schou, 2015); **(3)** in mixed fisheries, fishers may catch **overquota** fish when they continue fishing for other species whose quota is not yet exhausted; these fish, which may be (unavoidable, incidental) **bycatch** species or part of the targeted assemblage, must be discarded.

The LO, with Total Allowable **Catch** quotas (limiting **actual catches** rather than only **landings**), attempts to make an end to the implementation error caused by the landings quota system. However, it is expected that the EU will experience problems in **fully implementing** the Landing Obligation if the incentives for discarding continue to exist. For example, although the MLS will be abolished under the LO, fish smaller than **a minimum conservation reference size (MCRS)** are not permitted to be sold for human consumption and thus have a lower value. Therefore, incentives for discarding fish below MCRS and thus highgrading may continue to exist. In addition, in several areas choke-species problems may arise **in mixed fisheries** or fisheries with **unavoidable bycatch**. In an earlier report to the EP (Zimmermann *et al.*, 2015) we showed that it is possible to deal with potential **choke-species** problems in the Baltic Sea through several avenues. Nevertheless, unless the Landing Obligation is fully enforced, the incentives for discarding may remain also in the Baltic Sea.

Thus, the Common Fisheries Policy (CFP) can only be fully implemented if the Landing Obligation is **fully complied** with and catch limits are not exceeded. However, it is not yet clear how the catch limits and Landing Obligation will **be enforced** and how catches will be verified. The Regulation²³ leaves the documentation to the **Member States** (CEC, 2013b, Article 15.13):

*"For the purpose of monitoring compliance with the LO, Member States shall ensure detailed and accurate documentation of all fishing trips and adequate capacity and means, such as observers, **CCTV** and others. In doing so, Member States shall respect the principle of efficiency and proportionality."*

²³ CEC (2013b), *Regulation (EU) No 1380/2013 of the European Parliament and the council of 11 December 2013 on the Common Fisheries Policy, amending Council Regulations (EC) No 1954/2003 and (EC) No 1224/2009 and repealing Council Regulations (EC) No 2371/2002 and (EC) No 639/2004 and Council Decision 2004/585/EU.*

The level of accuracy is not specified, i.e. it is not stipulated whether all catches need to be counted or whether aggregated estimates will be sufficient. In the latter case, uncertainty margins should be applied.

As long as not all catches are observed, counted, documented, and verified, the Regulation leaves room for **implementation error**, in two ways:

1. Directly: Fishers may still catch (and discard) in excess of the quotas.
2. Indirectly: Removals will be known only with a certain **degree of uncertainty** to stock assessment scientists. This will lead to imprecise estimates, imprecise advice and imprecise management measures, for example too low or too high total allowable catch (TAC). Prior to the LO, this has been commonly the case. Scientists attempted to **estimate the removals** (including discards) through sampling trips with **observers** on board. Problems of reliability and representativeness of the samples may, however, increase under the Landing Obligation because fishers may fear that when scientists are aware of law violations, this information will be passed on to the **enforcement authorities**. To mitigate this problem, **data collection for science** (i.e. stock assessment) should be kept strictly separated from **data collection for enforcement purposes** (Mangi *et al.*, 2013). For example, it has been found that fishers report bycatch of rare species in scientific programs but not in their logbooks, although obligatory (Vølstad, personal communication).

5.1. Towards full catch accountability and results-based management

Hand in hand with the Landing Obligation the EU aims for a **result-based management (RBM)**. The concept of RBM in fisheries is proposed as a way for public authorities to delegate specific management and documentation responsibilities to **resource users** (reversal of the burden of proof). The concept comprises **three** defining features: **(1)** The **authorities** define measurable objectives for the utilization of fisheries resources; **(2)** the **resource users** are made responsible for achieving these objectives and for **(3)** providing **documentation** that allows for an audit of the extent to which they are met (Nolde Nielsen *et al.*, 2015). The EU legislator fixes objectives, targets and standards, and Member States cooperate **regionally** with input from all stakeholders to design the best suited tools to achieve these objectives and targets. This would entail moving away from the current prescriptive and detailed regulations (e.g. the technical measures), and reducing the complexity of current legislation. It would encourage the industry to **innovate** and to develop technology supporting the achievement of agreed aims.

If implementation error is to be avoided, the freedom from current complex and prescriptive legislation implied by RBM can only be provided to the actors (Member States, fishing enterprises) if either full trustworthiness or full proof of the catches can be ensured in return. Full documentation (i.e. proof) of the catch can be achieved by REM systems such as CCTV, sensor systems etc., but these systems are costly and fishers are often averse to being watched. Some Member States also expressed a dismissive attitude towards Remote Electronic Monitoring (REM).

To address this, various versions of **quid-pro-quo or tiered approaches** have been suggested (STECF, 2011; Mike Park, personal communication March 2013; Schou, 2015). In such approaches, **individual** fishers or **groups of fishers** (or Member States, which are hereafter also implied under 'groups of fishers') can choose between different **levels of monitoring**. Those under a **high level** of monitoring would **bear the costs** (monetary costs as well as psychological costs owing the above-mentioned aversion of being watched) but be

able to provide accurate catch information, whereas those under a **low level** of monitoring would **forego those costs** but provide **uncertain catch information**. The burden of that uncertainty would then fall on the latter (groups of) fishers with low level of monitoring; these fishers would either be under **more stringent and prescriptive regulations or be subject to a reduction of their quotas or both**. For those fishers providing uncertain information it would, for example, be assumed that their catches would amount to the upper end of a specified uncertainty interval. This could for example mean that (groups of) fishers with 100% observer coverage (e.g. by CCTV) would be allowed to catch and land the actual catch share they are entitled to, whereas (groups of) fishers without **observer coverage** would be assumed to discard according to historical rates and this catch would be deducted from their entitlement. There could be an intermediate level where catches are accounted for indirectly through data on catch methods and patterns, comparison with reference fleets, etc. and the quota deduction will be in proportion to the resulting uncertainty. This approach could also be a solution to the **"brace-and-belt"** issue identified in our second report to the EP (Stepputtis *et al.*, 2015): during the transition from "belt" to "brace" some groups of fishers could take their "belts" off and wear "braces" while other groups of fishers still wear "belts".

It should be noted that under full coverage by CCTV and/or other REM systems, **not all footage** needs to be observed **nor all data** need to be inspected. A risk-based approach would be to check only a certain proportion of the available footage/data but when suspicion arises that in a specific case the reported catches are not accurate, this specific footage/data will be subjected to greater scrutiny (Mangi *et al.*, 2013).

This tiered, *quid-pro-quo* approach can be taken **at any level** of groups of fishers, even at Member-State level where some Member States opt for full accountability and get their full quota share and other Member States opt for less accountability (perhaps for the time being in a transition period) and are subject to a reduction of their quota share because some discarding still has to be assumed. This is not counter the principle of Relative Stability if this is formulated in terms of **fishing opportunities** rather than **actual catch**: in order to be allowed to fully realise its fishing opportunity, a Member State must fully account for its catch, otherwise the Member States' historical discards are assumed to take place and are deducted from the catch share (partly, in case of intermediate levels of accountability).

In order to ensure buy-in – and hence compliance – from the fishing sector, such tiered *quid-pro-quo* approaches should be carefully **framed**. Should it be framed as a **"stick"** or as a **"carrot"**? A "stick" would be used where quota would be deducted if fishers do not take up the full monitoring. A "carrot" would be offered where fishers receive extra quota if they take up the full monitoring. The response to "carrots" versus "sticks" should be carefully considered. Human beings are known to be subject to loss aversion (Tversky and Kahneman, 1991). Loss aversion is encapsulated in the expression "losses loom larger than gains" (Kahneman and Tversky, 1979). It is thought that the pain of losing is psychologically about twice as powerful as the pleasure of gaining. In line with this notion, a behavioural-economics experiment found that a "stick" was sometimes more effective than a "carrot" in motivating people (Gächter *et al.*, 2009). All current and recent **EU pilot projects** with catch quota and Full Documented Fishery (FDF) have used the "carrot" and fishers seemed to be happy to opt in. On the other hand, the EU cod plan (EU, 2008) used the "stick" of effort reductions to motivate (groups of) fishers to take up cod avoidance measures and this was not well received by the fishing sector (Kraak *et al.*, 2013). Thus, observations in the EU fisheries appear contrary to the behavioural-economics experiment of Gächter *et al.* (2009). Perhaps a mixture of "sticks" and "carrots" may work best. In order to find out what kind of framing would lead to highest buy-in, directed research on the response of fishers to "sticks" and "carrots" or mixtures thereof is needed.

In order to incentivize uptake by fishers of FDF systems, it may be important to emphasize additional benefits of FDF (on top of full access to the fishing opportunities). The **quid-pro-quo approach** could, for example, stipulate that in return for FDF, the fishers will be subjected to less prescriptive rules and hence have more perceived freedom and **flexibility** in running their business (e.g. fishers applying FDF would have to comply with fewer technical measures on gear). FDF also presents an opportunity for fishing businesses to increase **efficiency by reducing waste (discards)** which would lead to **increased profits**; furthermore, fishers may see FDF as a method for industry-driven data collection, and full documentation of the fish supply chain (from net to plate) could bring strong **market incentives** through information on sustainability of the species, traceability and documentation on how the fish has been caught and treated onboard (Mangi *et al.*, 2013; David Stevens (fisher), personal communication and <https://youtu.be/zsuNxpH4alo>). The concepts of **traceability and transparency** could also be used in more innovative ways. Humans are not only subject to an aversion of being watched, but people may also like being watched when they are proud of what they are doing. In the eastern US, an idea has been trialed which draws on the effect of actors in a system knowing each other which may have a **positive impact on compliance**. In this trial fish products (in this case lobster) marketed and sold locally to the production area carry a Quick Response (QR) code which gives information about the individual catcher. In this way the actual seafood item sold is directly linked to the harvester. In other markets (meat products), this form of information promotes **trust from the consumer**, but in the fisheries case it may also promote compliance from the fishers by instilling in them a **greater sense of ownership** of the final product (Kraak *et al.*, 2015).

Further research on the “**being-watched**” effect should be conducted with experiments that are relevant to the specific settings encountered in fisheries management. The aversion to being watched is in agreement with the notion that **too much monitoring** may have the result that individuals feel they are not trusted and as a consequence become **less trustworthy** (Ostrom, 1998). In contrast, it has been well documented that people will be more likely to behave ‘prosocial’ (e.g. cooperate, comply) in non-anonymous situations, for example because it opens possibilities of direct or indirect reciprocity and reputation building (Kraak, 2011). Recent investigations have shown that subtle **cues of being watched** such as two stylized eye-like shapes on a computer screen suffice to change human behaviour and **reduce selfishness**; these eyeshaped cues seem to elicit unconscious hardwired reactions (Milinski and Rockenbach, 2007). Perhaps a way to exploit this human propensity without the disadvantage of eroding trust is to display a picture of “**watching eyes**” on the e-logbook screen (Kraak *et al.*, 2015).

The discussion below focuses on **factors** contributing to **implementation error** that involve the **behaviour of individual fishers**. It should be noted, however, that implementation error may also be caused by **processes** at **Member-State** level, for example the lack of political will to enforce regulations. Fishery **inspections** are extremely **heterogeneous** between Member States, where one Member State might regulate stricter and another is more lax. The discussion below, however, is based on the **behavioural sciences**, which deal with the psychology of individual behaviour and not with the ‘behaviour’ of larger, aggregate, entities such as states.

5.2. Crowding out of social capital and intrinsic motivation

Kraak (2011) framed the problem of **overfishing** in terms of the Tragedy of the Commons, where, according to standard rational economic theory, individuals are predicted to be unwilling to ‘cooperate’ for the common good through sacrificing catches in the short term, leading to overharvesting of the resource. However, over the last decades, a multitude of research has shown that humans often achieve outcomes that are ‘better than rational’ by

building conditions where reciprocity, reputation, and trust help to overcome the temptations of short-term self-interest (reviewed in Kraak, 2011). Factors enhancing '**cooperation**' include familiarity and non-anonymity with the possibility of direct or indirect reciprocity and reputation-building, face-to-face communication and physical contact, the threat of punishment or social exclusion (Kraak, 2011). In the case where the public good is an open-access common-pool resource, such as the ocean fisheries, an increase of the number of participants is negatively related to achieving cooperation (Weissing and Ostrom, 1991; Ostrom, 2001).

In section 5.1, we have already several times alluded to the notion that **compliance** is more likely when the people (in this case: fishers) whose **behaviour needs** to be regulated, buy-in to the rules. Fisheries management is in many cases a top-down bureaucratic exercise with centralized control (Daw and Gray, 2005). The regulations are viewed by the fishers as opposing rather than supporting their interests and this manifests itself as a reduced compliance to '*the letter*' as well as '*the spirit*' of the regulations (Kuperan and Sutinen, 1998; Hatcher *et al.*, 2000; Nielsen, 2003; Nielsen and Mathiesen, 2003; Kraak, 2011). The crowding-out hypothesis states that the willingness to **obey regulations voluntarily** depends on whether one is controlled or not (Bowles, 2008; Richter and van Soest, 2012). Counterintuitively, the tendency to control undermines any intrinsic motivations to comply voluntarily. The reason is that control signals mistrust, which directly affects other motivational factors, such as cooperation, reciprocity or being a good citizen. As a result, there is a hidden cost of control, as pointed out by Falk and Kosfeld (2006). The disturbing implication is that control can crowd out intrinsic motivations, calling for even stronger control, leading to a vicious cycle of mistrust and strong controls. **Behavioural economics** has established that regulations that are chosen by the individuals (for example via voting) are obeyed more, as they are perceived to be more legitimate (Vyrastekova and van Soest, 2003). It is apparent from the work of Ostrom that self-imposed rules and self-imposed sanctions work better (Ostrom, 2009).

Indeed, **fisheries systems** can be characterized by **mutual mistrust**, between regulators and fishers, between scientists and fishers, and among fishers themselves. Usually fishers are not expected to **voluntarily** take action to fish more sustainably. Often the institutional set-up is such that fishers are perceived as the antagonists. The key challenge for European fisheries is not to **prevent the erosion of social capital**, since there may be very little left – if it was there in the first place. Instead, the key question is how one can crowd in desirable behaviour by establishing a trusting relationship. The problem seems to be how to make the **transition** from the current **institutional dysfunction** and inertia. **Rebuilding of mutual trust** is likely a key issue, but this cannot be done simply on a short time scale.

The **lack of trust** may be exacerbated by the fact that fishers have lost respect for the rules and regulations because many of them do not seem to make sense, seem contradictory, or seem to provide perverse incentives. Also the new CFP is perceived by fishers to suffer from these problems. With the RBM approach with its fewer and simplified rules the challenge is to avoid **contradictory rules** and **perverse incentives** by careful design. As discussed above, this involves a thorough understanding about how fishers respond to "carrots" and "sticks" and to being watched.

In Europe there seems to be very **little trust** towards regulation among the fishers because of the top-down structure of EU fisheries management. There seems to be more room for **self-decision and co-decision in the US** (co-decision here meaning between regulators and fishers): on the US east coast the groundfish fisheries have collective quota programs, and on the US west coast fishers pool their quota (Holland and Jannot, 2012). These groups can set their own rules, not necessarily encoded in law, which means rules can more easily be

changed. These people were not necessarily connected in communities before; they came together because they have a **common problem** that can best be solved by **collective action**. For example, in **mixed fisheries** where vulnerable bycatch species effectively become the choke species, it is profitable to join in groups and share the individual small bycatch quota. In the case of New England, the fishers could choose their group, whereas in Alaska they were assigned to one. Several economic experiments have established that group choice is a key point to facilitate cooperative behaviour. If individuals can self-select into groups, there is a larger tendency to act in the group's interest and also to coordinate on a common cooperative strategy (Brekke *et al.*, 2011; Gurerk *et al.*, 2006). Also in Europe there are examples of fishers voluntarily pooling their quotas: in a **Danish village**, boat owners and fishers have established a cooperative company where they have bought quotas jointly, with the aim of securing the community of its present and future catch rights (Schou, 2011). In that way, the cooperative company replaces the Danish state as provider and guarantor of fishing rights (Schou, 2011).

Large group size and anonymity may be among the causes of the apparent lack of trust. Social capital and intrinsic motivation to cooperate tends to be higher in small groups of people who regularly interact with each other in non-anonymous ways. Indeed, as shown above, examples exist of fishers who have built up social networks and individual allegiances. It would seem therefore that a key principle of eliciting positive behaviour in the regulation of fisheries could be facilitating the organisation of fishers in small groups, and promoting interaction between the managers and the fishers at this group level.

On the other hand, the **in-group/out-group** setting of industry versus **managers** (or scientists or non-governmental organizations (NGOs)) may drive fisheries representatives to follow the '**party line**' and '**fight to the last ton**' in consultations, whereas autonomous individuals could perhaps be more flexible. Institutional inertia or '**group think**' can be a big impediment to achieving common objectives of sustainability. In the current system, fishers can be disempowered and become victims of institutional forces from above that are trying to control them. In order to increase social capital, it can be much more effective to bring the dialogue to the individual level. Individuals of different stakeholder groups could sit at the same table and express their interests and preferences in iterative rounds. This way, the individuals with different interests '**get a face**' and these individual expressions may trigger other individuals to re-evaluate their conditions, perhaps leading to greater areas of consensus (Kraak *et al.*, 2015).

Fishers may often distrust **scientists** (and vice versa). Kraak *et al.* (2015) discussed several reasons for this lack of trust and provided examples of possible solutions. Industry-science **collaborative projects** could be set up (building mutual trust) in which fishers could try new practices and scientists explore the consequences. In the US as well as in Europe various scientist-facilitated initiatives are arising where scientists process and display information that fishers provide to share among themselves, for example on catch per unit effort (CPUE) hotspots or bycatch rates of species that need to be avoided so that fishers can catch their quotas at lower impact to the ecosystem (e.g. O'Keefe and DeCelles, 2013; Hetherington, 2014). In collaboration with scientists the fishing industry can create fishery management plans which comply with management policies. In the Netherlands fishing organisations have started to hire ex government scientists to help them check the assessments and advice and develop plans.

The theory of crowding out does not only state that **control** may undermine intrinsic motivations to comply, but also that monetary incentives may undermine such motivations. In experiments and in the field it has been found that sometimes financial incentives induced more self-interested behaviour, even after they were withdrawn (Bowles, 2008). For example,

in a study by Cardenas *et al.* (2000) experiments were run with people in rural Colombia who are confronted with a common pool problem in their daily life. In the experiment subjects were asked to decide how much timber to extract from a forest. The scenario presented was that harvesting had an adverse effect on water quality (as is actually the case in the study region), posing a cost on everyone in the group. The game was played first without any regulations in place, while at a later stage an extraction norm was introduced that was enforced by a mild probabilistic fine. Cardenas *et al.* (2000) found that subjects reduced their extraction level immediately after the regulation was introduced, but started extracting more aggressively after realizing that consequences were rather mild. Strikingly, in the last rounds, extraction levels were higher with the regulation than without. As a result, **payoffs** were significantly **lower** when individuals were confronted with a **formal rule** than in its absence; the weak official rule interacted with the internal norms of the subjects and destroyed their intrinsic motivation to cooperate. Richter and van Soest (2012) reviewed similar experiments, such as the one where imposing a fine on parents arriving late to collect their children at day care increased the number of late-coming parents, or the one where small honoraria for seminar speakers may increase the probability of declining the invitation. These results suggest that the application of **non-monetary incentives in fisheries management** should be explored, along with other factors enhancing intrinsic motivation such as moral reminders, non-anonymity, small group size, face-to-face communication. Nevertheless, Bowles (2008) as well as Richter and van Soest (2012) warn that the loss of social capital may, to a high extent, be irreversible and that from the reviewed experiments it cannot simply be concluded that regulations or sanctions should be abolished.

5.3. Voluntary compliance

In most countries, the **standard approach** to obtaining **fisher compliance** is to deter rule violations through investments in enforcement activities, including at-sea patrols, dockside monitoring, and observer programs. This approach is built on the assumption that the occurrence of **fishery offenses** is solely a function of the **perceived costs and benefits** of an offense, such as the gains derived from the rule violation, the likelihood of detection, and the severity of the penalties (Becker, 1974). However, modern criminology (e.g., Tyler, 2006) and behavioural economics (Mazar *et al.*, 2008) recognize that many people comply with rules, either in part or full, because they believe it is **the right thing to do**. For instance, tax compliance is much higher than deterrence models would predict (Frey and Torgler, 2007). Conversely, a study among Danish fishers (Nielsen and Mathiesen, 2003) reported that they “feel they are taken hostage by an illegitimate management system, and thus feel it is morally correct not to comply”. When we witness unethical behaviour, our own morality erodes (Ariely, 2012). Cheating can be socially contagious (Gino *et al.*, 2009): as long as we see members of our own social groups behaving in ways that are dishonest, it is likely that we too will recalibrate our internal moral compass and adopt their behaviour as a model for our own. **Tax compliance**, for example, varies widely across European countries and a high correlation has been found between perceived tax evasion and tax morale (Frey and Torgler, 2007). And if the member of the in-group happens to be an authority figure – a parent, senior manager, teacher, or someone else we respect – chances are even higher that we will be dragged along. Individuals may even feel pride about breaking the rules, resulting in groups of people committing crimes because everyone is doing it. Perhaps compliance could be enhanced by publishing stories of complying fishers in the fishing press and thereby foster pride about sustainable fishing practices.

In **laboratory experiments** Mazar *et al.* (2008) found that (1) the amount of **dishonesty** is largely insensitive to either the expected external benefits or the costs associated with the deceptive acts; (2) causing people to become more aware of their internal standards for honesty by **moral priming** decreases their tendency for deception; and (3) increasing the ‘**degrees of freedom**’ that people have to interpret their actions increases their tendency

for deception. For instance, Mazar *et al.* (2008) found that non-monetary crime targets (i.e., property rather than money) can increase economically incentivized dishonesty in a laboratory setting. Similar laboratory studies by Mead *et al.* (2009) found that mental tiredness also increases cheating. These two studies suggest that **violation of fishing regulations** could at least in part be **exacerbated by a lack of moral reminders**, the opportunity to steal a **non-monetary asset** (i.e., fish), and the **mental tiredness** of fishers. Mazar *et al.* (2008) suggest that understanding dishonesty has important implications for designing effective methods to curb it. The **costs** of obtaining a particular level of fisheries compliance through enforcement activities could potentially be reduced through complementary investments in activities that increase voluntary compliance.

Studies (e.g., Mazar *et al.*, 2008) have indicated that honesty can be enhanced by asking people to **sign a statement** in which they declare their commitment to honesty before taking part in a task rather than after (e.g. signing the honesty statement on the tax income declaration form at the top rather than at the bottom). In fisheries this finding could be applied by making **fishers sign the logbook at the top** / in the beginning (Kraak *et al.*, 2015). The e-log system could have a confirmation screen which requires the operator to acknowledge that they are filling the form out accurately before the electronic system can receive data input (Kraak *et al.*, 2015). This could be combined with a picture of “watching eyes” displayed on the screen (see the above discussion of ‘being watched’) (Kraak *et al.*, 2015).

5.4. Quota allocation, transferability, ITQ, group quotas

It is generally thought that individual transferable quotas (ITQ) can alleviate **overcapacity** and facilitate **balancing** of the catches to the quotas (Costello *et al.*, 2008) (provided that the catches are monitored and the catch limits enforced). The capital that is thus set free can be used for other purposes (Schou, 2011). In the face of catch quotas under the LO, it would be of great benefit to facilitate quota transferability not only within but also between Member States (see also Zimmermann *et al.*, 2015). ITQ are often considered to have **negative societal effects** such as **capital** concentration and **closure of coastal communities**. This can be mitigated by designing ITQ management to serve societal policies in terms of structural development of the fleet and allocation priorities (Schou, 2011). Policy can for example restrict concentration of ITQ ownership, define **fleet segments** with no inter-segment transferability, reserve quota shares for coastal fisheries or geographical regions, and facilitate new entry e.g. young fishers entry (Schou, 2011), and they should perhaps not necessarily be handed out for free and in perpetuity. Instead fishing rights could be handed out through a lottery or bidding system (Bromley, 2009).

Group-allocated catch shares may **foster social motives** and cooperation (although it can also bring back the ‘race for fish’ among the group members that the individual quota system aims to bring an end to). Fisheries management could set up a structure in which **several levels of organisation** are offered to which **individual fishers can opt-in** (e.g. voluntary pooling of quotas); each levels has its benefits and costs, but because the individuals can choose themselves, there would be greater acceptance of the disadvantages of the chosen setting.

Operating in **groups/cooperatives** may be more or less attractive to fishers: a perceived advantage may be risk sharing and a perceived disadvantage may be that the individual surrenders his individual decision-making for the sake of democratic group decision-making. However, if self-decision in small groups and **bottom-up designing of rules** is deemed to promote compliance and ‘prosocial’ behaviour, Member States may want to design **policies where operating in groups/cooperatives is incentivized**, e.g., by giving more freedom from top-down regulations to groups/cooperatives than to individuals.

There are significant **costs** of managing a group/cooperative that need to be covered. To the extent that social behaviour of fishers in **small groups decreases the negative externalities to society** caused by non-compliance, overfishing, capital concentration, etc., policies can be designed that effectively **subsidize those groups/cooperatives**. This can be done in the form of setting aside a portion of the Member State's quota for **such social initiatives**, or else by financial instruments.

5.5. Conclusions and recommendations

In conclusion, much of the past implementation error has been caused because the **complex top-down control** and **lack of trust** have undermined potential intrinsic motivation to fish sustainably. Compliance is not necessarily a function of the economical pros and cons of **rule violation: compliance** may be higher or lower, depending on intrinsic motivations. An increased level of **self-decision** may lead to **more buy-in** to sustainable fishing practices and voluntary compliance to catch limits and the LO. All else being equal, people in **small and self-selected groups** are inherently more likely to behave "prosocial". However, transition towards a system allowing for more freedom from top-down regulation, with more self-governance, may be difficult. Some **key recommendations** are given below.

- Let **actors** choose, in a quid-pro-quo tiered approach, between various levels of realisable fishing opportunities with relative freedom from prescriptive measures while paying the appropriate (monetary, psychological) costs of FDF.
- Increase **regulators'** trust of fishers through FDF.
- Increase **fishers' trust of regulators** by designing simpler legislation, with non-contradictory rules, not leading to perverse incentives.
- Increase **fishers' trust of scientists and scientists' trust of fishers** by setting up industry-science partnerships and collaborative research.
- Increase **fishers' mutual trust and their intrinsic motivations** to fish sustainably by facilitating and encouraging fishers to organise themselves in small groups with common interests.
- Allow for several levels of organisation to choose from and allow for **self-selecting of group membership**.
- Incentivize the organisation of fishers into groups through the provision of, e.g., **extra quota**, relative **freedom from top-down regulation**, or through **financial instruments**.
- Allow for **self-decision** within small groups of fishers, where their own rules and sanctions do not necessarily have to be coded in law.
- Allow groups of **fishers to decide** themselves on the methods of FDF.
- Do not only rely on **monetary incentives** and monetary **penalties**; these may crowd out intrinsic motivations.
- Publish good (and bad?) behaviour of named fishers in the (local or fishers') press. **Publishing good behaviour** of named fishers may be a **non-monetary incentive** because it fosters pride of being a sustainable (good) fisher. Publishing bad behaviour of named fishers may be a non-monetary incentive because it poses the threat of social exclusion; but a perverse effect may be that it fosters pride of behaving badly and the bad behaviour becomes contagious. To be on the safe side, stay with publishing good behaviour only.
- Establish **QR codes (Quick Response Codes)** that link a product to an individual fisher to **foster pride** of being a sustainable fisher.
- Use **moral reminders** in the e-log software, such as pictures of watching eyes on the screen and a requirement to sign a statement of accurate reporting at the start of their e-log session.

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